Handbook of Research on

Social, Economic, and Environmental Sustainability in the Development of Smart Cities

Andrea Vesco and Francesco Ferrero

IGI GLOBAL
DISSEMINATOR of KNOWLEDGE

Handbook of Research on Social, Economic, and Environmental Sustainability in the Development of Smart Cities

Andrea Vesco
Istituto Superiore Mario Boella, Italy

Francesco Ferrero
Istituto Superiore Mario Boella, Italy

A volume in the Advances in Environmental Engineering and Green Technologies (AEEGT) Book Series

Information Science REFERENCE
An Imprint of IGI Global

Managing Director: Lindsay Johnston
Managing Editor: Austin DeMarco
Director of Intellectual Property & Contracts: Jan Travers
Acquisitions Editor: Kayla Wolfe
Production Editor: Christina Henning
Development Editor: Brandon Carbaugh
Cover Design: Jason Mull

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA, USA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Handbook of research on social, economic, and environmental sustainability in the development of smart cities / Andrea Vesco and Francesco Ferrero, editors.
pages cm
Includes bibliographical references and index.
ISBN 978-1-4666-8282-5 (hardcover) -- ISBN 978-1-4666-8283-2 (ebook) 1. City planning. 2. City planning--Technological innovations. 3. Urbanization. 4. Technological innovations. 5. Sustainability. I. Vesco, Andrea, 1978- II. Ferrero, Francesco, 1975-
HT166.H363 2015
307.1'216--dc23

2015003772

This book is published in the IGI Global book series Advances in Environmental Engineering and Green Technologies (AEEGT) (ISSN: 2326-9162; eISSN: 2326-9170)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

All work contributed to this book is new, previously-unpublished material. The views expressed in this book are those of the authors, but not necessarily of the publisher.

For electronic access to this publication, please contact: eresources@igi-global.com.

Advances in Environmental Engineering and Green Technologies (AEEGT) Book Series

ISSN: 2326-9162
EISSN: 2326-9170

Mission

Growing awareness and an increased focus on environmental issues such as climate change, energy use, and loss of non-renewable resources have brought about a greater need for research that provides potential solutions to these problems. Research in environmental science and engineering continues to play a vital role in uncovering new opportunities for a "green" future.

The **Advances in Environmental Engineering and Green Technologies (AEEGT)** book series is a mouthpiece for research in all aspects of environmental science, earth science, and green initiatives. This series supports the ongoing research in this field through publishing books that discuss topics within environmental engineering or that deal with the interdisciplinary field of green technologies.

Coverage

- Alternative Power Sources
- Cleantech
- Electric Vehicles
- Air Quality
- Waste Management
- Contaminated Site Remediation
- Green Transportation
- Sustainable Communities
- Biofilters and Biofiltration
- Green Technology

IGI Global is currently accepting manuscripts for publication within this series. To submit a proposal for a volume in this series, please contact our Acquisition Editors at Acquisitions@igi-global.com or visit: http://www.igi-global.com/publish/.

The Advances in Environmental Engineering and Green Technologies (AEEGT) Book Series (ISSN 2326-9162) is published by IGI Global, 701 E. Chocolate Avenue, Hershey, PA 17033-1240, USA, www.igi-global.com. This series is composed of titles available for purchase individually; each title is edited to be contextually exclusive from any other title within the series. For pricing and ordering information please visit http://www.igi-global.com/book-series/advances-environmental-engineering-green-technologies/73679. Postmaster: Send all address changes to above address.

Titles in this Series

For a list of additional titles in this series, please visit: www.igi-global.com

Green Services Engineering, Optimization, and Modeling in the Technological Age
Xiaodong Liu (Edinburgh Napier University, UK) and Yang Li (British Telecom, UK)
Information Science Reference • copyright 2015 • 315pp • H/C (ISBN: 9781466684478) • US $225.00 (our price)

Innovative Materials and Systems for Energy Harvesting Applications
Luciano Mescia (Politecnico di Bari, Italy) Onofrio Losito (Politecnico di Bari, Italy) and Francesco Prudenzano (Politecnico di Bari, Italy)
Engineering Science Reference • copyright 2015 • 413pp • H/C (ISBN: 9781466682542) • US $235.00 (our price)

Progressive Engineering Practices in Marine Resource Management
Ivelina Zlateva (Independent Researcher, Bulgaria) Violin Raykov (Institute of Oceanology, Bulgaria) and Nikola Nikolov (Technical University of Varna, Bulgaria)
Engineering Science Reference • copyright 2015 • 456pp • H/C (ISBN: 9781466683334) • US $245.00 (our price)

Promoting Sustainable Practices through Energy Engineering and Asset Management
Vicente González-Prida (University of Seville, Spain) and Anthony Raman (NTEC Tertiary Group, New Zealand)
Engineering Science Reference • copyright 2015 • 402pp • H/C (ISBN: 9781466682221) • US $235.00 (our price)

Handbook of Research on Advancements in Environmental Engineering
Nediljka Gaurina-Medjimurec (University of Zagreb, Croatia)
Engineering Science Reference • copyright 2015 • 660pp • H/C (ISBN: 9781466673366) • US $345.00 (our price)

Soft Computing Applications for Renewable Energy and Energy Efficiency
Maria del Socorro García Cascales (Technical University of Cartagena, Spain) Juan Miguel Sánchez Lozano (University Centre of Defence at the Spanish Air Force Academy, Technical University of Cartagena, Spain) Antonio David Masegosa Arredondo (University of Granada, Spain) and Carlos Cruz Corona (University of Granada, Spain)
Information Science Reference • copyright 2015 • 408pp • H/C (ISBN: 9781466666313) • US $235.00 (our price)

Optimum Design of Renewable Energy Systems Microgrid and Nature Grid Methods
Shin'ya Obara (Kitami Institute of Technology, Japan)
Engineering Science Reference • copyright 2014 • 430pp • H/C (ISBN: 9781466657960) • US $235.00 (our price)

Nuclear Power Plant Instrumentation and Control Systems for Safety and Security
Michael Yastrebenetsky (State Scientific and Technical Centre for Nuclear and Radiation Safety, Ukraine) and Vyacheslav Kharchenko (National Aerospace University- KhAI, Ukraine, and Centre for Safety Infrastructure-Oriented Research and Analysis, Ukraine)

IGI GLOBAL
DISSEMINATOR OF KNOWLEDGE
www.igi-global.com

701 E. Chocolate Ave., Hershey, PA 17033
Order online at www.igi-global.com or call 717-533-8845 x100
To place a standing order for titles released in this series, contact: cust@igi-global.com
Mon-Fri 8:00 am - 5:00 pm (est) or fax 24 hours a day 717-533-8661

List of Contributors

Table of Contents

Detailed Table of Contents

This chapter provides an insight into what is meant by a Smart City and the underlying factors that make a city smart. The authors answer the question of "what constitutes a smart city" by presenting a multi-faceted approach including a detailed analysis of classical smart city definitions, attributes of a smart city, industry viewpoints and efforts by standards developing organizations. Through this approach, a common theme is established which best describes a smart city. The content of this chapter can therefore form the basis of developing a standard definition of a global smart city, and subsequently can be used to develop a framework to measure the performance of a smart city. The authors also propose a definition which in their view provides a reasonably holistic description of a smart city. However, they recognize that a smart city may mean different things to different stakeholders, and therefore has a strong dependence on the "lens" through which a smart city is viewed.

This chapter challenges recent mode 2 accounts of smart cities and in particular, the idea they are an index of the future internet. Adopting the triple helix model of knowledge production, it studies smart cities, not as the emergent technologies of economic transactions, but in terms of civil society's support for the integration of Web2.0-based information and communication platforms into their regional innovation systems. This reveals that no matter how technologically advanced such an internet-driven reinvention of cities may appear, being smart is something which reaches beyond this. Beyond this and towards policies, leadership qualities and corporate strategies that not only serve the knowledge economy, but

Smart cities are envisioned to enable a vast amount of services in urban environments, so as to improve mobility, health, resource management, and, generally speaking, citizens' quality of life. Most of these services rely on pervasive, seamless and real-time access to information by users on the move, as well as on continuous exchanges of data among millions of devices deployed throughout the urban surface. It is thus clear that communication networks will be the key to enabling smart city solutions, by providing their core support infrastructure. In particular, wireless technologies will represent the main tool leveraged by such an infrastructure, as they allow device mobility and do not have the deployment constraints of wired architectures. In this Chapter, we present different wireless access networks intended to empower future smart cities, and discuss their features, complementarity and interoperability.

Smart cities embed information and communication technologies (ICT) to create interactive milieus that constitute a bridge between the physical and the digital world. In their attempt to improve citizens' quality of life through a more efficient use and sustainability of resources, smart cities might, however, also raise important concerns as regards the privacy and confidentiality of personal data flows. Insofar as the design of a city's telecommunication infrastructure is likely to affect the nature of social dynamics and human interactions, it should, ideally, be achieved through a coordinated, citizen-centric approach combining integrated ICTs with active citizen participation and intelligent physical, digital and informational resource management. This chapter analyzes the case of community mesh networks as an example of grassroots decentralized communication infrastructures, whose architecture design has important implications for the deployment and configuration of smart cities.

The widespread availability of smartphones with on-board sensors has recently enabled the possibility of harvesting large quantities of monitoring data in urban areas, thus enabling so-called crowdsensing solutions, which make it possible to achieve very large-scale and fine-grained sensing by exploiting all personal resources and mobile activities in Smart Cities. In fact, the information gathered from people, systems, and things, including both social and technical data, is one of the most valuable resources available to a city's stakeholders, but its huge volume makes its integration and processing, especially in a real-time and scalable manner, very difficult. This chapter presents and discusses currently available crowdsensing and participatory solutions. After presenting the current state-of-the-art crowdsensing management infrastructures, by carefully considering the related and primary design guidelines/choices and implementation issues/opportunities, it provides an in-depth presentation of the related work in the field. Moreover, it presents some novel experimental results collected in the ParticipAct Crowdsensing Living Lab testbed, an ongoing experiment at the University of Bologna that involves 150 students for one year in a very large-scale crowdsensing campaign.

This chapter introduces a range of analytics being used to understand the smart city, which depends on data that can primarily be understood using new kinds of scientific visualisation. We focus on short term routine functions that take place in cities which are being rapidly automated through various kinds of sensors, embedded into the physical fabric of the city itself or being accessed from mobile devices. We first outline a concept of the smart city, arguing that there is a major distinction between the ways in which technologies are being used to look at the short and long terms structure of cities, and we then focus on the shorter term, first examining the immediate visualisation of data through dashboards, then examining data infrastructures such as map portals, and finally introducing new ways of visualising social media which enable us to elicit the power of the crowd in providing and supplying data. We conclude with a brief focus on how new urban analytics is emerging to make sense of these developments.

This chapter addresses the smart city concept as a first step towards the formulation of a new socially-improved urban concept which may be defined as that of the "people-friendly city". This new task involves the employment of IT tools, but using new methods and pursuing different goals other than mere numerical information. In terms of the urban environment, this means that cities should be designed for people, and planning practitioners should be able to understand citizens' needs, communicate with them and involve them in a collaborative process. Therefore, an overview of the implications of smart cities for urban planning is followed by a more detailed analysis of Planning Support Systems (PSS) as innovative tools for enhancing the process of delivering a more inclusive and people-friendly urban environment. The lessons learnt from the application of the PSS tool is then illustrated in order to define the potentialities and key points for the development of similar tools.

Foreword

When associated for instance to a card, the adjective "*smart*" doubtlessly assumes the meaning of "*intelligent*". But, if it is used to identify the character of a City - an animated and sensible body - the same adjective discloses a range of qualifying traits, and the city appears at the same time *intelligent*, *dynamic*, *enjoyable*, *culturally open*, *friendly* and *sustainable*. If adopted, this wide interpretation raises a number of potential questions about the *Smart and Sustainable City* perspective.

For instance: what kind of reflections is this perspective casting in an urban context? Does a *Smart City* only address the ways the energy is produced, distributed and used or, in a wider sense, does it offer a new framework to deal with the challenges the urban communities are facing? Is it worth venturing forward with the ambitious plan of creating a *City* which is at the same time smart, sustainable and socially inclusive? What are the issues to be faced and resolved in the narrow time span the environmental conditions are prescribing?

These are just some of the questions the *wide Smart City* concept raises. On the whole, they are significantly enlarging the energy and sustainability-driven objectives launched in the Strategic Energy Plan adopted in 2010 by the European Commission. On the other hand, the experience gained in these last years has revealed that a purely *technical* and *economic* approach to the *Smart City* is doomed to failure if social processes and personal attitudes are not considered as fundamental variables of the changes the *Smart City* perspective is aiming at.

Inevitably, the *wide Smart City* view opens up a comprehensive spectrum of new and interdependent problems of a multidisciplinary character and extends the horizon over which the *City* growth strategies are defined. And its ambitious objectives may raise some first-impact opposition in society due to the radical discontinuities they are suggesting. This view is in fact challenging the energy consumption and generation models, urban mobility schemes, service processes, goods production mechanisms, citizens' ways of sharing resources and even the community's habits. But the urgent need for these transformations, together with the advantages they produce for the benefit of present and future generations, is now fully understood in industrially-advanced societies and they are rapidly affecting the growth traits of developing countries. As such, the *smart and sustainable* perspective of our cities is fully ingrained in the fundamental questions of our age.

The strategic vision that should inspire the City's development in the *smart and sustainable perspective* is a dynamic representation of the urban system with a long-term horizon. The representation is backwards, inspiring present choices, and in the opposite direction it is absorbing the new signals deriving from technological, economic and social advances.

The economy of sustainability reflects this model: the changes adopted today are inspired by the perspective emerging from the interactions of the social dynamics, namely research, industrial, political and societal processes (triple helix). At the same time these changes create new knowledge (both coded and tacit knowledge) which contributes in turn to the continuous updating of the future perspective. It is through the disposition of society to *build-up* its future that the urban community is playing an active role in the development process. So, the construction of smart and sustainable conditions for our cities should be inspired much more by the question: *what do we want to realise for the society of the future and how?* rather than adopting the more conventional argument: *let's try to foresee where the actual trends will take us so we can be ready to react accordingly*.

This view does not constrain society to a unique approach on how the new conditions can be realised and, at the same time, it revives a positive attitude and gives rise to a latent desire for participation and awareness in an epoch which is densely populated by uncertainty and alienation.

Looking at the *smart and sustainable city* through the watermark of this tangle of complex problems may discourage even the most inspired people. On the other hand, the plausible vision of such a desirable city should catalyse the best capacities and the most creative spirits to pledge intelligence and social sensibility to create a safe and enjoyable future for the present and coming generations. This was the firm belief that inspired the book editors and the scientific committee when choosing the chapters and in arranging them in a way that makes the contributions readable as components of a single conceptual framework. But the most valuable constituent of the book was the authoritativeness of the authors and their willingness to follow the agreed scheme. In doing so, the authors cover such a wide spectrum of skills and sensibilities that it is fair to say that a significant portion of the *Smart City* issues one can imagine have been considered and analysed from a variety of standpoints.

The geographical distribution of the authors adds further value to this collection: the different views and proposals reflect a variety of urban characteristics and interdependencies. This certifies that the *Smart City* puzzle is far from accepting a single solution and confirms the faculty of local communities to find their own path to sustainability, in contrast to the mental uniformity the globalised economy is generating in several circumstances.

The contributions the book gathers include both methodological aspects and proposals for specific solutions. The breadth and the richness of the arguments deserves some effort to recover a comprehensive view of them, a sort of collection of hints with some remarks gluing them in a consistent figure (one among the many possible).

Indubitably, Smart City is explicitly or implicitly viewed as an unrepeatable opportunity to re-define the character and the growing mechanisms of urban agglomerations, the places where the greatest concentration of human communities live. The use of the adjective *unrepeatable* makes sense since it recalls the urgency of the environmental issues and social criticalities in (or generated by) urban concentrations. All together, they constitute the collection of interdependent challenges and corresponding *objectives* that form the *vision* of the future City. This vision, with the peculiar characteristics of the City it refers to, has to be conceived (and continuously re-defined) as the horizon the City-innovation actions must address. In this sense, the improvement of citizens' quality of life and the low-carbon character of the new status represent the *strategic objectives,* and the composite metrics measuring the level of improvement they have reached deserve careful analysis. The composite nature of each objective lies in the series of interlaced factors playing a role in its achievement. For instance, reducing the energy footprint of heating in buildings means adopting construction methods or advanced temperature control mechanisms that create new jobs: a fundamental contribution to social wellbeing.

But the *way* these objectives are reached also forms part of the vision. In other words, the *method* used to make societal transformations is in its turn fundamental because urban smartness is *growing by doing* and the way the relevant actions are performed is a key education factor for the social body. So, the actions should not only adopt an opportunistic approach to the final objective, but guarantee that they offer a real opportunity to create widespread *knowledge* and consciousness, to increase the *participation* level and the *sense of commonality*. This methodological approach may lead to the natural rise of new forms of *communities*, based on a renewed interpretation of the *common goods* concept. The emergence of the Energy communities is a good example of how the *way* adopted to build a low carbon society may create unexplored forms of socialisation.

The adoption of a common and transparent *vision* and the assumption that this vision must inspire the innovation choices on the way to smartness raises some important questions about the governance of the overall urban transformation. The social community must adopt a *planning* and a *continuous measurement* approach in defining and managing the multiplicity of *actions* to be set-up. The *plans* should identify the most effective sequence of *changes* by considering the nature of the systems to be modified, the environmental priorities and the economic constraints. The form of any kind of *change* (e.g. *gradual* or *discontinuous*; *technology* or *process- driven*; acting on the *demand* or on the *supply* side) must be identified through a *sensitivity* analysis able to anticipate its potential impact and to identify the key factors affecting its effectiveness. This exercise also *highlights* the type of *regulatory* tools and *policies* that can produce the expected achievements. The praxis of *measurement* is essential to certify the effect of any change, to verify the *economic sustainability* and the *social acceptability* of the involved urban transformations and to re-direct the future plans.

Urban plans and the continuous measurements of the effects suggest that quite an active role has to be taken by the Public Authority in the Smart City adventure. This role is not only necessary in terms of guaranteeing public benefits but also in terms of the intangible and direct knowledge of the societal processes to be governed and transformed in the spirit of Smart City. The active presence of the Public Authority must enable the transformations to take place without threatening the autonomy of the business forces.

The planning and measurement approach implies an extensive use of urban *modelling* and representation based on the abstraction of the complex processes under analysis: an unexplored opportunity for *interdisciplinary* research, interweaving different disciplines like social science, economics and engineering under common objectives. For instance, the financial solutions suited for the business models enabled by technological and process-driven discontinuities may directly involve the citizens' willingness to participate through mechanisms like crowd funding.

So, the *vision* and a new *strategic approach* are expected to drive the way to smartness. But what are the *objects* and the *processes* on which the *actions* will hopefully take place? Here the range of possibilities and the interdependencies are even wider. The basic and enabling tools to make these actions possible are Information and Communication Technologies. Thanks to their *generic* character, these techniques have a large spectrum of possible applications and a high propensity to be re-used to resolve a number of different problems. The power of these techniques lies first of all in the networking and interaction capability among humans and machines in any combination, even though their control is lying in any case under the human intentionality. Another important role ICTs play is to bridge the gap between the real and the virtual words in the many cases where a process or part thereof must be modelled in order to generalise a function or project the effects of an action in a situation to come. A good example is the dimensioning of local electricity grids in presence of a high penetration of electric vehicles, where the re-charging demand has to be estimated in order to design the grid capacity and the control requirements.

An integrated view of urban life can offer great advantages, due to the possibility of sharing the immense amount of data that are in principle available in a highly *digitalised* environment (e.g. through mobile phones, monitoring networks and embedded processing capabilities). In most cases these data are generated for a very specific reason and making them open to different uses (after appropriate processing) can generate new knowledge and disclose a number of application capabilities that are difficult to understand *a priori.* The Smart City perspective then nurtures the paradigm of *big data* as a common good for society. If the individual citizen agrees to share their (anonymous) data while using a public service, then they contribute to enriching the common knowledge which, in turn, makes the public service more accurate and attractive, favouring, cyclically, further knowledge creation. Mobility in an urban environment and traffic management issues reflect this concept: mobile devices and the vehicles themselves produce a lot of data for their own functionality, and the same data, when suitably processed, can improve mobility performance and produce more powerful ways to manage mobility itself.

In the second half of the last century, the consciousness of the *Limits of growth* (Club of Rome) started to flourish significantly and was strongly supported by the parallel growth of philosophical attention to a new *form of responsibility* the human being must develop towards other *forms of life* and *future generations* (Hans Jonas).

A wide elaboration has been developed since and the culture of sustainability has hopefully grown significantly in the last few decades, also because we are progressively experiencing the distressing evidence of the unwise use of natural resources (see, for instance, desertification and the pace of destructive weather phenomena).

Despite its unavoidable incompleteness, this book is an attempt to demonstrate, through a variety of examples and arguments, how a wider concept of sustainability can be achieved at urban level thanks to a multiplicity of actions and sensibilities that can be set up and mature in the framework of a *smart and sustainable city*.

Giovanni Colombo
Istituto Superiore Mario Boella, Italy

Giovanni Colombo *graduated in Electrical Engineering from Politecnico di Torino. Following a long management experience in the Telecommunication and IT sectors, from 1989 to 2006 he covered key roles at Telecom Italia Labs (the research centre of Telecom Italia). He was head of research and Chief Technology Officer (CTO) of Telecom Italia Labs, and finally head of long-term research at Telecom Italia. For the European Commission (EC), he was chairman of the Mobile Domain, clustering European R&D projects on mobile and wireless communication technologies (1997-1999), and member of the IST Advisory Group (ISTAG) supporting the EC in defining R&D policies within ICT. He was member of the Governing Board and Executive Committee of the European Institute of Innovation and Technology (EIT) from 2008 to 2012. In 2010 he was appointed vice president and director of Istituto Superiore Mario Boella. Throughout his career he has held an ongoing teaching role at Politecnico di Torino as an adjunct professor.*

Preface

The urban population has surpassed the rural population in the world and is expected to increase dramatically in the coming years to the point that by 2050, almost 70% of the world population will live in cities. Many of the cities around the world will become megacities with more than 10 million inhabitants.

The issues related to the growth of the urban population are among the most important challenges of our time. The bulk of energy consumption and carbon emissions occur in urban areas. This implies that cities are the first place where the innovations which must guide us towards a new model of sustainable development, *i.e.* a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development [WCED], 1987), should be experimented. For us this is the key meaning of urban "smartness".

Sustainable development is not possible without taking social, economic and environmental issues into account at the same time. A sustainable economy enables cities to make the long-term investments necessary to build and maintain adequate infrastructure, to provide effective services, to develop an open social environment for its citizens and to foster and support business activities, without compromising the natural environment.

The main issue is not only reducing waste, consuming less energy and non-renewable resources, but designing and managing cities so that all the processes that take place inside them become fully sustainable from a social, economic and environmental point of view.

All the actions at the basis of urban development really succeed when they also support the capability of citizens to create healthy and livable communities. Socially sustainable cities provide equitable opportunities for all, promote and encourage diversity, and foster opportunities to meet and exchange and provide open and participatory governance while ensuring that basic needs are meet and guaranteeing a good quality of life. This social dimension reminds us that sustainable growth is not possible without the engagement of citizens, their awareness of the importance of sustainable behavior and their willingness to play an active role in this change.

The Smart City concept addresses the issues of urban development with the emphasis on social, economic and environmental sustainability, *i.e.* triple sustainability. Fulfilling the objective of being smart is a long journey and it can only be reached if all stakeholders, *i.e.* government, industry, academia and citizens, work together in the same direction.

Information and Communication Technologies (ICTs) are an enabling factor of a Smart City. Looking at the city as a complex system, ICTs simplify the management of complexity and allow us to approach sustainable development in an integrated fashion. ICTs allow us to measure and analyze complex phenomena and facilitate short and long-term planning and decision-making in real time. However ICTs are not the sole ingredient of a Smart City; in fact, great importance is placed on human capital which, due to its access to information and communications, can contribute to the development process.

This book was conceived to foster the urban sustainability culture, helping readers to understand this articulated concept with a strongly interdisciplinary approach. Unlike other books organized around the application domains, this book addresses the theme with a focus on the role of the different ingredients that constitute a Smart City: the role of citizens, the role of governance, the role of ICTs, the importance of urban data and of the technologies that can support decision-making, and the crucial role of finance, which can transform the decisions into reality.

The Section "*Smart and Sustainable Cities"* introduces the concept of Smart Cities and their sustainability objective.

In Chapter 1, *Sekhar & Ramita Kondepudi* provide an insight into what is meant by a Smart City and the underlying factors that make a city smart. The authors answer the question of "what constitutes a smart city" by presenting a multi-faceted approach including a detailed analysis of classical definitions, attributes, industry viewpoints and efforts by standard developing organizations. The approach establishes a common theme which allows the authors to conclude by proposing a comprehensive definition of Smart City which attempts to incorporate as many of the different aspects as possible.

Leveraging on the idea that cities are smarter when government, industry and universities work together (i.e. the triple helix model of knowledge production), *Mark Deakin* studies smart cities in Chapter 2, not as the emergent technologies of economic transactions, but in terms of civil society's support for the integration of Web2.0-based information and communication platforms in their regional innovation systems. This reveals that no matter how technologically-advanced such an internet-driven reinvention of cities may appear, being smart is something which reaches beyond this. Beyond this and towards policies, leadership qualities and corporate strategies that not only serve the knowledge economy, but which are also smart in allowing cities to cultivate the creativity of the internet as the information and communication technologies of regional innovation systems.

The concepts of sustainable development and the smart city addressed by previous authors have been quite fashionable in the policy arena in recent years. A review of the literature in the field highlights several areas of interest and a number of important dimensions to the concept of the smart city, but also a lack of appropriate metrics, methodologies and tools with which both experts and policy makers can evaluate the performance of sustainable cities. The measurement of urban performance is one of the important ways in which one can assess the complexity of urban change and judge which projects and solutions have been successful or not. Therefore, in Chapter 3 *Patrizia Lombardi & Silvia Giordano* introduce a new system for measuring urban performance. This system is the result of two years of joint cooperation between the authors and the International Initiative for a Sustainable Built Environment (iiSBE) members group, and is based on previous research findings in the field of evaluation systems for the sustainable built environment. The new approach is useful for evaluating smart and sustainable urban redevelopment planning solutions as it is based on benchmarking approaches and multi-scalar quantitative performance indicators (KPIs), from individual building level to city level.

The Section "*Smart Citizens and Governance*" addresses the importance of the active role of citizens as well as the fundamental role of governance in fostering and driving smart and sustainable behavior.

Although Smart Cities are based on ICTs, people, with their knowledge, habits, experiences, culture and behavior, remain at the heart of concerns. In Chapter 4 *Elsa Negre & Camille Rosenthal-Sabroux* address the knowledge brought by citizens as a key factor that can contribute towards improving the smartness of cities. The discussion focuses on the centrality of citizens, the ICTs as a tool for divulging and retrieving knowledge, and the environment, or rather, cities in constant evolution where ICTs and people are nested.

Just as the concept of Smart City is not the same around the world, the series of steps by which cities become more livable and resilient, hence smart, are also not the same everywhere. In Chapter 5, *Tebarek Lika & Gebrye Kefelew* cite the case of the development and management of cooperative housing green areas and street trees in Addis Ababa, Ethiopia, to highlight how a lack of awareness on the part of the citizens and government, together with limited institutional capacities, a lack of coordination among stakeholders and the lack of clear ownership and enforcement mechanisms, are serious problems that affect the ability of cities to meet their objective of being smart.

Urban Living Labs are socio-digital innovation environments in realistic city life conditions based on multi-stakeholder partnerships that effectively involve citizens in the co-creation and co-production of new or reformed public services and infrastructures. *Grazia Concilio & Francesco Molinari*, in Chapter 6, explore the growing phenomenon of Urban Living Labs and analyze the nature of related innovations in terms of "City Smartness" – a mantra for local governments worldwide which are having to address increasingly complex problems with fast-diminishing financial resources. The authors go on to briefly overview the urban governance models emerging in such environments and finally focus on the challenges posed by these models as a result of the integration between the "technology push" (i.e. the Smart City vision) and "human pull" (i.e. the Urban Living Lab concept and approach). Many cities worldwide are developing their Smart Agendas; some of them are using significant resources to implement technological solutions for innovative community services. Despite this global "fever", the authors remain skeptical that interpreting the concept of urban smartness in a way that is technology-driven rather than human-driven may allow us to grasp the full potential of the dimension of Urban Smartness.

The Section "*Smart Cities at the Crossroad among Energy, Mobility and ICT*" focuses on the role of ICTs as enablers of smartness in specific application domains.

Starting with the Energy domain, *Catalina Spataru et al.*, in Chapter 7, provide a discussion on how current multi-scale energy systems are expressed by a multitude of data and simulation models, and how these modelling approaches can be (re)designed or combined to get a clearer picture of a multi-scale energy system. It aims to address the knowledge gap in energy system modelling in order to better understand its existing and future challenges. Due to the accelerating ICT integration in virtually all modern systems, the frontiers between operational algorithms embedded in hardware and modelling control strategies are becoming fuzzier; the authors believe that the paradigm of modelling intelligent urban energy systems for the future has to be constantly evolving. The chapter concludes with the need to build a holistic, multi-dimensional and multi-scale framework in order to address tomorrow's urban energy challenges.

There is no single urban energy system, but – like the city itself – a system of sub-systems addressing different spatial and temporal scales, spatially ranging from buildings to blocks, districts and the city, temporally ranging from aggregated real time data to hourly, monthly and, finally, annual totals. Therefore, *Wolfgang Loibl et al.*, in Chapter 8, discuss ICT solutions for planning, controlling, maintaining, observing and assessing the urban energy system in order to improve its sustainability and take into account energy efficiency.

Nowadays, residential hybrid energy systems are moving from being a pure theoretical exercise to real applications for new urban areas. The growing interest related to the needs of reducing pollution, the phasing out of fossil fuel resources and the need to safeguard the environment have led to a large number of studies and solutions to reduce fuel consumption and to manage energy sources in a better way, leading to an innovative concept of the city where smart infrastructures are in place. *Luca Tamburini et al.*, in Chapter 9, introduce the concept of hybrid energy systems, namely buildings that can exploit both renewable energy sources and the grid. On top of it, a system manager schedules the usage of electrical appliances to minimize the electricity bill for the user while providing peak shaving and load balancing services to utilities and service providers. The scheduling algorithm is able to act on the system, arranging appliances according to users' habits and needs and the state of the energy sources involved.

Mobility is central and is in steady evolution in our society. The transport sector is one of the reasons for energy consumption and pollution emissions. Vehicles, both personal and commercial, have become a ubiquitous form of transportation in the developed world. The internal combustion engine has been the predominant energy choice for vehicles for more than a hundred years. The car industry is in the midst of a major technological transformation in identifying alternative sources of energy to power vehicles due to two driving forces: environmental pollution prevention and the depletion of fuel resources. This driver for developing "smarter" solutions to create a "smarter planet" is crucial to advancing the science behind electric vehicles (EVs). As alternative methods for creating energy are being sought, there is an increased interest in electric vehicles as one solution to lessen our dependence on fossil fuels. EVs have been in existence since the mid-19th century, and electric locomotion has been commonplace in many other vehicle types such as trains. *Promiti Dutta et al.*, in Chapter 10, discuss the feasibility of EVs in smart cities by exploring the different types of EVs and the advantages and challenges faced by EVs in penetrating the market, and outlining the state-of-the-art research and technologies that are driving the creation of newer and better EVs for adoption in the smart cities of tomorrow.

The innovation in the urban mobility field does not only encompass the design of green vehicles but also the smart management of traffic, infrastructure and services. Poor or inadequate traffic management in urban environments is responsible not only for congestion, causing a significant waste of time and frustration, but also unnecessary fuel consumption and environmental harm through pollution. There are two major technological developments which provide opportunities to develop novel transportation systems for the Smart City: new sensors and the wireless networks connecting them, and the advent of battery-powered vehicles which can drastically reduce harmful emissions and conserve energy. *Christos G. Cassandras,* in Chapter 11, describes three new systems that affect transportation in Smart Cities. First, a Smart Parking system which assigns and reserves an optimal parking space based on the driver's cost function, combining proximity to destination and parking cost. Second, a system which uses the same framework as Smart Parking to optimally allocate electric vehicles to charging stations and reserve spaces for them. Finally, the traffic light control problem by viewing the operation of an intersection as a stochastic hybrid system and developing a stochastic flow model for it. Using Infinitesimal Perturbation Analysis (IPA), the author derives on-line gradient estimates of a cost metric with respect to the controllable green and red cycle lengths and iteratively adjusts light cycle lengths to improve (and possibly optimize) performance, as well as adapt to changing traffic conditions.

A very interesting analysis of policies and practices about mobility in the Asia-Pacific region is provided in Chapter 12 by *Hoong-Chor Chin & Yueying Wang*. With the anticipated acceleration in motorization and the potentially-damaging unplanned urban sprawl, the region will be threatened by problems of traffic congestion, pollution and road hazards. Several countries in the region have taken a variety of proactive measures to ensure that urban transportation systems are designed and operated in a smart, sustainable and safe manner. The authors identify the policies and practices in South Korea, Japan, China, Taiwan, Singapore and Australia, and seek to draw lessons from these on how transportation schemes can be implemented elsewhere.

Smart cities are envisioned to enable a vast amount of services in urban environments, so as to improve energy, mobility, health, resource management, and, generally speaking, citizens' quality of life. Most of these services rely on pervasive, seamless and real-time access to information by users on the move, as well as on the continuous exchanges of data between millions of devices deployed throughout the urban surface. It is thus clear that communication networks will be key to enabling smart city solutions, by providing their core support infrastructure. In particular, wireless technologies will represent the main tool leveraged by such an infrastructure, as they allow device mobility and do not have the deployment constraints of wired architectures. *Hervé Rivano et al.*, in Chapter 13, present different wireless access networks intended to empower future smart cities and discuss their features, complementarity and interoperability.

Insofar as the design of a city's telecommunication infrastructure is likely to affect the nature of social dynamics and human interactions, it should, ideally, be achieved also through a coordinated, citizen-centric approach combining integrated ICTs with active citizen participation and intelligent physical, digital and informational resource management. *Primavera De Filippi*, in Chapter 14, analyzes the case of community mesh networks as an example of grassroots decentralized communication infrastructures whose architecture design has important implications for the deployment and configuration of smart cities.

The Section "*Data and Decision-Making in Smart Cities*" emphasizes the importance of gathering and of analyzing urban data in order to provide support to decision-making and to foster the design of new applications by sharing them in an open paradigm.

The widespread availability of smartphones with on-board sensors has recently enabled the possibility of harvesting large quantities of monitoring data in urban areas, thus enabling so-called crowdsensing solutions, which make it possible to achieve very large-scale and fine-grained sensing by exploiting all personal resources and mobile activities in Smart Cities. In fact, the information gathered from people, systems, and things, including both social and technical data, is one of the most valuable resources available to a city's stakeholders, but its huge volume makes its integration and processing, especially in real-time and in a scalable manner, very difficult. *Paolo Bellavista et al.*, in Chapter 15, present and discuss currently available crowdsensing and participatory solutions. After presenting the current state-of-the-art crowdsensing management infrastructures, by carefully considering the related and primary design guidelines/choices and implementation issues/opportunities, the authors provide an in-depth presentation of the related work in the field. Moreover, they present some novel experimental results collected in the ParticipAct Crowdsensing Living Lab testbed, an ongoing experiment at the University of Bologna.

After the previous discussion on innovative approaches for gathering data from the urban system, *Michael Batty et al.*, in Chapter 16, introduce a range of analytics being used to understand the smart city, which depend on data that can primarily be understood using new kinds of scientific visualization. The authors focus on short-term routine functions that take place in cities which are being rapidly automated through various kinds of sensors embedded into the physical fabric of the city itself or accessed from mobile devices. They first outline a concept of the smart city, arguing that there is a major distinction between the ways in which technologies are being used to look at the short- and long-term structure of cities, and then focus on the shorter-term, first examining the immediate visualization of data through dashboards, then examining data infrastructure such as map portals, and finally introducing new ways of visualizing social media which enable us to elicit the power of the crowd in providing and supplying data.

Urban data are also exploited with a specific social intention in the smart city. Thus, *Giulia Melis et al.*, in Chapter 17, address the smart city concept as a first step towards the formulation of a new socially-improved urban concept which may be defined as that of the "people-friendly city". This new task involves the employment of IT tools, but using new methods and pursuing different goals other than mere numerical information. In terms of the urban environment, this means that cities should be designed for people, and planning practitioners should be able to understand citizens' needs, communicate with them and involve them in a collaborative process. Therefore, an overview of the implications of smart cities for urban planning will be followed by a more detailed analysis of Planning Support Systems (PSS) as innovative tools for enhancing the process of delivering a more inclusive and people-friendly urban environment. Finally, the lessons learnt from the application of a PSS are addressed to define the potentialities and key points for the development of similar tools.

Salvatore Di Dio et al., in Chapter 18, present the social initiative "TrafficO2". This initiative is designing a support system for decision-making in the field of transportation that tries to push commuters towards more sustainable mobility by offering concrete incentives for each responsible choice. Data from the users' smartphones are processed and exploited in accordance with the Social Computing paradigm to influence citizens' urban transport habits and reduce negative externalities.

The Section "*Funding Smart Cities*" provides insight on how to fund Smart City projects and initiatives with a particular focus on Europe.

The intense pressure being brought to bear by the increasing diversity in European urban development patterns calls for innovative funding mechanisms to promote smart sustainable urban development, most notably in the energy sector. Currently in Europe, various policy initiatives support sustainable urban development through financial engineering mechanisms operating at municipal and regional scales. *Francesca Medda et al.*, in Chapter 19, review the main financial mechanisms focusing on energy, and in particular on urban investments committed to a highly energy-efficient and low-carbon economy. Within this framework they assert that, in order to achieve the EU's sustainable urban development objectives, specific European financial instruments will need to be considered as viable key investment options. The authors also discuss the importance of ESCOs and crowdfunding as essential funding sources for community energy projects, and suggest that European policy should recognize their importance.

Finally, *Eugenio Leanza & Gianni Carbonaro*, in Chapter 20, present a research agenda focusing on the role of smart, socially inclusive, sustainable cities in furthering the balanced, equitable development of the European economy. In order for cities to play this role it is necessary to start from a vision of the city as a system of interlinked assets, and from the need to manage these assets in a sustainable way using a methodology broadly based on the principles of corporate finance. This research agenda aims to span areas of expertise and policy dimensions that are often fragmented, in order to lead to improved diagnostics and strategic investing. In Europe, this vision of the city and of the urban management process will enable better bottom-up policy delivery and address the challenges facing the European economy by facilitating the adaptation of European city systems to diverging spatial growth patterns, youth unemployment, ageing populations, migration patterns, and increasingly sharp financial divergences among different territorial systems.

With the precise intention of providing as broad a vision as possible, this book has been developed with the collaboration and contribution of passionate professors, researchers and experts from all around the world and from a vast array of disciplines. This is in line with the idea of the Editors that real *smartness* can only be built on top of collective wisdom. The authors and the members of the Editorial Advisory Board live and work in more than 20 different cities in the US, Europe, Africa and Asia-Pacific.

Andrea Vesco
Istituto Superiore Mario Boella, Italy

Francesco Ferrero
Istituto Superiore Mario Boella, Italy

REFERENCES

World Commission on Environment and Development (WCED). (1987). *Our common future*. Oxford, UK: Oxford University Press.

Acknowledgment

We would like to acknowledge the help of all the people involved in this project. Without their support, this book would not have become a reality. First, our sincere gratitude goes to the authors of the chapters, who contributed their time and expertise to this book. Second, we wish to acknowledge the valuable contributions of the reviewers to improving the quality, coherence, and presentation of the content of the chapters. The authors also served as referees; we greatly appreciated their dual role. Third, our thanks go to all of the members of the Editorial Advisory Board. Special thanks also go to Giovanni Colombo for inspiring the Smart City Program that formed the basis of this book and for writing the foreword.

During the preparation of this book many things have happened, some of which very important. Andrea, already husband to Daniela, received the gift of seeing the birth of his two children, Marta and Tommaso. Francesco experienced the joy of marrying Chiara. This book is dedicated to you.

Andrea Vesco
Istituto Superiore Mario Boella, Italy

Francesco Ferrero
Istituto Superiore Mario Boella, Italy

Section 1
Smart and Sustainable Cities

Chapter 1
What Constitutes a Smart City?

Sekhar Kondepudi
National University of Singapore, Singapore

Ramita Kondepudi
Harvey Mudd College, USA

ABSTRACT

This chapter provides an insight into what is meant by a Smart City and the underlying factors that make a city smart. The authors answer the question of "what constitutes a smart city" by presenting a multi-faceted approach including a detailed analysis of classical smart city definitions, attributes of a smart city, industry viewpoints and efforts by standards developing organizations. Through this approach, a common theme is established which best describes a smart city. The content of this chapter can therefore form the basis of developing a standard definition of a global smart city, and subsequently can be used to develop a framework to measure the performance of a smart city. The authors also propose a definition which in their view provides a reasonably holistic description of a smart city. However, they recognize that a smart city may mean different things to different stakeholders, and therefore has a strong dependence on the "lens" through which a smart city is viewed.

INTRODUCTION

Governance, technology, communication, transport, infrastructure, people, economy, environment, natural resources, innovation, and quality of living are only some of the characteristics that factor into the definition of a "smart city." There is no one unique definition that fits all. Rather, what a smart city is can be highly subjective, depending on the circumstance and the lens through which it is viewed.

To date, there is no standardized definition of a smart city, although some are starting to be proposed. In recognition of this gap, several Standards Developing Organizations (SDOs) including the International Telecommunication Union (ITU), International Electrotechnical Commission (IEC) and the International Standards Organization (ISO), have all started efforts in earnest, to develop a globally accepted definition of a "smart city". The ITU Focus Group on Smart Sustainable Cities has proposed the following definition of a smart sustainable city:

DOI: 10.4018/978-1-4666-8282-5.ch001

A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.

Why is a smart city important enough to warrant a standardized definition?

The answer lies in the rapid urbanization of our planet – with projections of 70% of the global human footprint to be located in an urban environment by the year 2050. As per the United Nations (2013) World Economic and Social Survey, Africa, Asia and other developing regions will house 80% of the world's urban population in the coming years. While urbanization can bring progress, it can also pose challenges: how do we achieve sustainability concurrently with urban growth? Social, economic and environmental issues have become tightly interconnected. Information and Communication Technologies (ICT) provide cities with platforms to become "smart" via the efficient management of city services. These can range from water, energy, waste, transport to government, education and healthcare. The construct of a smart city should result in higher living standards for its inhabitants, especially through the conscious application of ICT.

This chapter will provide an overview of a smart city in a systemic and methodical fashion. Different points of view will be presented, and common attributes and functions of a smart city will be developed thematically using multiple sources including industry, standards organizations and other studies related to indicators and indices of a smart city. A common set of terms will then be developed to best describe these multiple views in a comprehensive and holistic manner. Finally, a proposed definition of a smart city shall be presented by the authors, with full recognition that there are many other possible variants depending upon the subjectivity of the "lens" of a given smart city stakeholder.

APPROACH

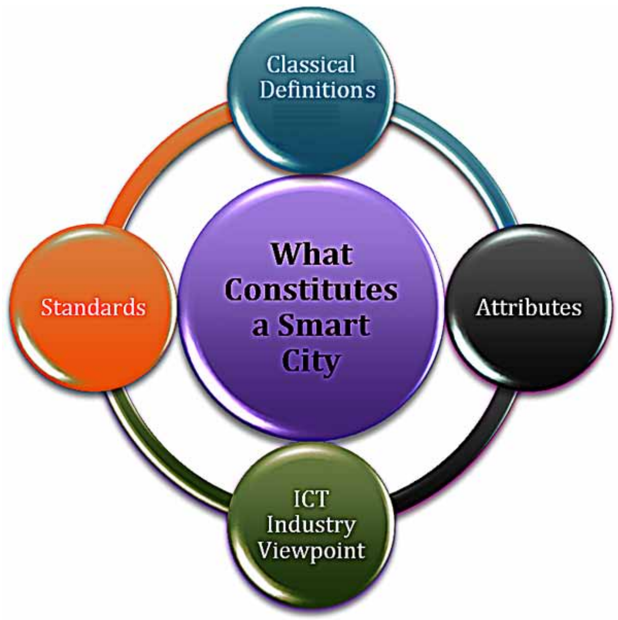
In considering what exactly is a smart city, one of the challenges is that there are so many viewpoints, each valid in its own right. A smart city has many different connotations and interpretations. All of these different facets are important, but a holistic overview is essential to the process of finding an answer to the question "What constitutes a smart city?". A comprehensive description which addresses these different viewpoints will be invaluable. In order to develop such a description, a detailed and methodical analysis was developed in the form of a combination of top-down and bottom-up approaches.

Figure 1 illustrates the approach followed, and this chapter describes the journey towards establishing "What constitutes as Smart City".

The following steps were followed:

1. Conduct a comprehensive data collection exercise to develop an understanding of what a smart city means from different viewpoints:
   a. A study of the many different classical definitions found in the literature.
   b. Identify what are some of the key common attributes for a smart city.
   c. An understanding of the different ICT centric corporate / industry views of a smart city.
   d. A look into what the different standards development organizations (SDOs) are doing in relation to smart cities.
2. Develop a common vocabulary based on the above data collection to help establish the characteristics of a smart city in terms of Categories, Vertical Themes and Key Words. This vocabulary can be used to de-

Figure 1. Approach for understanding what constitutes a smart city



fine a smart city depending upon the "lens" through which it is viewed, and by whom.

3. Propose a comprehensive definition of a smart city based on the above common parameters, which tries to address the different viewpoints, acknowledging that many other variants may be equally valid and credible.

CLASSICAL SMART CITY DEFINITIONS

Perhaps the best place to start is to consider the classical smart city definitions to be found in open literature, including scientific journals and technical papers. In order to ensure a well-balanced study, multiple sources were chosen to research these classical definitions: (1) Individual, (2) Academic, (3) Corporate, (4) Government, (5) Non-Profits, (6) SDOs, (7) Internet, (8) Market Research and (9) the Press.

The following section is based on extensive research that has been conducted by the authors as part of a study conducted under the auspices of the ITU Focus Group on Smart Sustainable Cities (ITU, 2014). Only the salient parts of the results are discussed here and interested readers are referred to the ITU report for greater details. Based on the above research, over one hundred and twenty (120) definitions of a smart city were collected and analyzed in detail.

Example Definitions

Table 1 is a small sample of some of the definitions set out in the ITU (2014) report. All the definitions were analyzed to identify the top keywords and characteristics that make up a smart city. Some words such as Smart and City are implicit and mentioned in almost every description, so are not explicitly considered as a separate keyword.

Table 1. Example and illustrative smart city definitions

Source	Reference	Definition(s)	Keywords
Academic	Meijer, Albert, and Manuel Pedro Rodríguez Bolívar. "Governing the smart city: Scaling-Up the Search for Socio-Techno Synergy." T EGPA 2013 (Edinburgh, September) Permanent Study Group on E-Government, 2013, https://www.scss.tcd.ie/disciplines/information_systems/egpa/docs/2013/BolivarMeijer.pdf	"We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."	ICT, High quality of life, Natural resource management, Participatory governance, Transport infrastructure, Communication infrastructure, Economic growth, Sustainability
Corporate	Hitachi. "Smart city Overview." *Smart Cities: Hitachi*. Hitachi, http://www.hitachi.com/products/smartcity/vision/concept/overview.html .	Hitachi's vision for the smart city seeks to achieve concern for the global environment and lifestyle safety and convenience through the coordination of infrastructure. Smart Sustainable Cities realized through the coordination of infrastructures consist of two infrastructure layers that support consumers' lifestyles together with the urban management infrastructure that links these together using IT.	Coordinated infrastructure, lifestyle safety, lifestyle convenience, urban infrastructure, IT
Government	Giffinger, Rudolf, et al. "Smart Cities Ranking of European Medium-sized Cities." Centre of Regional Science, Vienna UT, Oct. 2007. Page 10. http://www.smart-cities.eu/download/smart_cities_final_report.pdf	"A city well performing in a forward-looking way in [economy, people, governance, mobility, environment, and living] built on the smart combination of endowments and activities of self-decisive, independent and aware citizens."	Economy, people, governance, mobility, environment, quality of living, forward looking, aware citizens, self-decisive citizens, independent citizens.
International Agency	"Smart Sustainable Cities & Smart Statistics", Government of Italy, Contribution No. FG-SSC-0014, ITU Focus Group on Smart Sustainable Cities, Turin, May 2013. http://ifa.itu.int/t/fg/ssc/docs/1305-Turin/in/fg-ssc-0014-Italy.zip	It's a city with a large, efficient and widespread technological network that fosters dialogue between citizens and everyday objects. It integrates the huge amount of information available to generate intelligence and *improve daily life in a lifestyle that is increasingly "smart"*. It combines innovation with the environment, mobility and quality of life. It is a new phenomenon, complex and rapidly changing. Technological innovation moves in several directions (*green buildings, smart mobility, e-health, e-government,…*)	ICT, integrated, quality of life, innovation, environment, mobility, green buildings, health, environment governance
Conference	Ajit Jaokar, "Big Data for Smart Cities", Smart Cities Industry Summit, London, Sept 2012, http://www.opengardensblog.futuretext.com/wp-content/uploads/2012/09/informa-smart-cities-ajit-jaokar.pdf	7 important elements in most cases of smart cities • Sensible - sensor sensing the environment • Connectable - networking devices bring the sensing information to the web • Accessible - broader information about our environment is published on the web, and accessible to the web user (web) • Ubiquitous - the user can get access to the information through the web, but more importantly it is accessible at any time, and in any place (mobile) • Sociable - the user acquired the information and published it though his social network (social network) • Sharable - shared are not limited to data, but also to the physical object, when some objects are in free status, people can be notified and use them. (web, mobile) • Visible/augmented - to retrofit the physical environment, render the hidden information visible not only to individuals on mobile devices but seen by the naked eye in more border range of the physical places like street signs.	Sensor monitoring, internet connectivity, information availability, mobile, visible

Analysis

Based on the 100+ definitions assembled, it was found that the following eight (8) broad categories best characterize a smart city:

1. Quality of Life / Lifestyle
2. Infrastructure & Services
3. ICT / Communication / Intelligence / Information
4. People / Citizens / Society
5. Environment / Sustainable
6. Governance / Management / Administration
7. Economy / Resources
8. Mobility

Since the above categories may have non-specific meanings or multiple connotations, in order to minimize any subjectivity the following descriptions and explanations for each category are provided below:

Quality of Life / Lifestyle

According to the World Health Organization (1997), Quality of Life is an individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns.

Infrastructure

According to Sullivan and Sheffrin (2003), Infrastructure refers to the physical and organizational structures and facilities needed for the operation of a society or enterprise in order to ensure the functioning of an economy. There are two types of infrastructure – physical (examples: Buildings, Roads, Utilities) and services (examples: education, and healthcare). ICT and associated infrastructure are represented elsewhere using another keyword. It can be generally described as a set of interconnected structural elements (physical-physical, service-service and service-physical) that provide the framework to support an economy.

ICT / Communication / Intelligence / Information

ICT (Information and Communications Technology) is an umbrella term that typically ranges from hardware to software, as described by Nokia Solutions and Networks (n.d.). It includes the usage of "smart" devices such as smartphones, tablets and PCs used especially to communicate. In the context of a smart city, ICT permits a better quality of life in areas such as security, healthcare, and transport for citizens; more efficient power supply for industries; remote working and e-commerce for businesses; and entertainment and communications for individuals.

People / Citizens / Society

People are the clear differentiator when we compare a "smart" city with a "digital" city. Digital implies a computing-centric view, whereas smart implies the inclusion of the human factor. People are smart in terms of their skills and educational levels, as well as the quality of social interaction in terms of integration and public life and their ability to open up to the "outside" world. Key elements include well-educated citizens, life-long learning, and human capital availability

Sustainable / Environment

As described by the International Telecommunications Union, ITU (2012), "sustainability is improving the quality of human life while living within the carrying capacity of supporting eco-systems". Among other definitions, currently "sustainability" is used as an umbrella term for all human activity designed to meet current needs without hindering the ability to meet the needs of future generations in terms of economic, environmental and social challenges.

Governance

According to the Smart Governance Network (n.d.), smart governance includes e-government, the efficiency and mobile working. It is about the future of the public services, community leadership, and continuous improvement through innovation. It relates to using ICT to facilitate and support better planning and decision making, and to improving democratic processes and transforming the ways that public services are delivered.

Economy / Resources

The Smart Economy as described by the Government of Ireland (2008), combines the successful elements of the enterprise economy and the innovation or 'ideas' economy while promoting a high-quality environment, improving energy security and promoting social cohesion.

Mobility

Mobility has been described by the California Department of Transportation or Caltrans (2010) to include not only the mode of transport but also the requisite infrastructure for that mode of transport. Without infrastructure, mobility is reduced. Hence, transport should also be considered implicit when discussing mobility in the context of Smart Cities, since innovation and IT can improve not only transport but also mobility.

Summary

Each of the above eight categories has a set of descriptive components, and Table 2 depicts the relative importance of each of the categories in terms of the number of occurrences in the 100+ definitions studied.

Table 2 provides a good insight into what could be considered as key words describing a smart city – topics such as Well-being, Lifestyle, Society, Sustainable, ICT, Economy, Governance all resonate really well in terms of what the vibrancy of a city should be and the need to include those in defining a smart city. The percentage occurrence column is indicative as to the number of times these terms were found in the 100+ definitions studied.

Let us now move on to another approach to classifying smart cities, via the following four key pivots of Quality of Life, Urban related aspects, Sustainability and Intelligence. Some of these overlap with the above analysis, but are developed within a different frame of reference.

Table 2. Smart city categories and descriptors

Category	Components	%Occurence
Quality of Life & Lifestyle	Lifestyle	7%
	Well Being	
	Happiness	
Infrastructure & Services	Development	18%
	Services	
	Buildings	
	Health, Safety & Security	
	Utilities	
	Education	
	Energy	
	Water	
	Electricity	
ICT, Communication, Intelligence, Information	Modern	26%
	ICT	
	Technology	
	Interconnected	
	Information	
	Communication	
	Intelligent	
	Integrated	
	Systems	
	Advanced	
	Design	

continued on following page

Table 2. Continued

Category	Components	%Occurence
People, Citizens, Society	Community	11%
	Accessible	
	People	
	Urban	
	Society	
	Actively	
	Innovation	
	Aware	
	Participatory	
Environment & Sustainability	Efficient	16%
	Sustainable	
	Adaptable	
	Optimal	
	Environment	
	Resources	
	Natural	
Governance, Management & Administration	Governance & Administration	9%
	Management	
	Capital	
	Operational	
	Public	
	Solutions	
	Vision	
Economy & Financials	Economy	8%
	Investments	
	Business	
	Competitive	
Mobility	Mobility	5%
	Transport	
TOTAL		100%

ATTRIBUTES OF A SMART CITY

Another equally valid approach to viewing a smart city is through the following four "pivots".

1. **Quality of Life / Society:** The city is designed for its inhabitants i.e. the citizens. Quality of Life (QoL) is a recurrent theme. One of the most important factors in creating a smart city is ensuring that the QoL is consistently improving.
2. **Urban / City:** Looking through an "urban" lens while planning the city allows us to consider multiple aspects that are specific to city life as opposed to a rural environment.
3. **Sustainability:** Sustainability is implicit in a smart city. Topics include energy, climate change, pollution and waste, society, economics and health. The authors believe that it is this topic that deserves to be discussed explicitly considering how important this subject is to a smart city.
4. **Intelligence or Smartness:** The role of urban "intelligence" should make use of ICT and technologies with the implicit or explicit ambition to improve economic, social and environmental standards. Commonly quoted aspects of smartness include Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Living and Smart Environment.

It should be noted that technology and infrastructure are not explicitly included in the above analysis; while these are essential and critical for a smart city, they are really enablers for a final goal / result as cited above and are discussed separately.

Quality of Life / Societal Aspects

At the end of the day, a city needs to provide for its inhabitants (citizens) and try to ensure that their everyday lives are as seamless and full as possible. Several organizations have attempted to frame the Quality of Life (QoL) as a key ingredient for a smart city. This section reflects the views of the World Health Organization (WHO), Mercer, The Economist Intelligence Unit – EIU, and Japan's NTT. These were chosen since they are representative of the overall QoL for a citizen.

The World Health Organization (WHO) (1997) defines Quality of Life as an individual's perception of his/her position in life in the context of the culture and value systems in which he/she lives and in relation to his/her goals, expectations, standards and concerns. Such a definition is fairly broad in that it covers individuals' physical health, psychological state, level of independence, social relationships, personal beliefs and their relationship to salient features of their environment. In an urban environment, the exact meaning of QoL may be subjective, but in general most citizens hope for better education, healthcare, living conditions, housing, and guaranteed employment. It is fair to say that every human being aspires to improving their QoL, regardless of their current state.

According to Azkuna (n.d), society and people distinguish a digital city from a smart city. People are smart in terms of their skills and educational levels. The quality of social interaction, such as integration, public life and people's ability to open up to the "outside" world, also play a major role in defining society. Key elements include well-educated citizens, life-long learning, and human capital availability.

An annual Quality of Living Index and Ranking report published by Mercer (2102), stems from the trends of globalization and the notion of the world becoming increasingly "flat." It is a good proxy for determining the importance of life for a transient global population, as people immigrate across the world. With over 450 cities included in the comparison, the criteria listed for a good QoL help form qualitative perceptions. These can then be further analyzed to form an objective assessment of living quality in a city. New York City is presented as a basis for the rankings, due to historical context. The Economist (2004) presents a discussion of a 'quality of life' index based on extensive surveys. The index maps results of subjective life-satisfaction surveys to objective metrics such as wealth, health, family life, crime, trust in government and so on. Tsuda et al. (2007) developed a gross social feel-good (GSF) index framework which includes a "happiness" index. The index considers both the pros and cons of sustainability (an environmental, social and economic balance) in relation to the terms of ICT services.

Analyzing the above studies leads to a set of common dimensions related to Quality of Life (QoL), which are important for a city. These dimensions are summarized in Table 3.

Urban/City Indicators

Smart Cities are urban, and therefore it is important to account for specific aspects of urban living when defining smart cities. The Global City Indicators Facility (GCIF), The United Nations Global Compact Cities Programme, Siemens Green City Index and The Economist Intelligence Unit (EIU) Hotspots Index provide a representative view of urban indicators. Many of these indicators are common across these different sources, and it is instructive to synthesize the information into a common set of indicators and attributes in some form of thematic manner.

City Indicators (n.d) are based on GCIF (an organization supported by the World Bank) which provides an established set of city performance indicators using a globally standardized approach.

Table 3. Quality of life dimensions

Theme	Example Attributes
Family / Societal	• Comfortable Lifestyle - Standard of Living • Degree of satisfaction with society (Happiness) • Family & Community Support Structures • Gender Equality&Social Equity
Economics / Infrastructure	• Economic Environment - Job Security, Employment, GDP • Housing • Public Services & Transport • Technology and Innovation • Safety – Physical, Accidents, Crime
Political / Governmental	• Political Stability & Civic Engagement • Social Environment • Medical & Health Considerations • Schools & Education

There are a total of 120 indicators, subdivided into *profile, basic provision (core),* and *supporting indicators.* All the indicators fall into two broad categories – (1) City Services and (2) Quality of Life. City Services include Education, Energy, Finance, Recreation, Fire Emergency Response, Governance, Health, Safety, Solid Waste, Transportation, Urban Planning, Potable Water and Waste Water. Quality of Life aspects include Civic Engagement, Culture, Economy, Environment, Shelter, Social Equity, Technology and Innovation – all of which are a subset of the comprehensive list summarized in the previous section. The GCIF is also working to create a series of future indices including competiveness, energy use, greenhouse gas, governance, recreation and culture, social capital, subjective wellbeing, creativity, and water quality. The Global Compact Cities Programme (n.d.) is an integral part of the United Nations effort in this space. The goal is to provide cities with the opportunity to display specific attributes at different levels of engagement. The program operates globally and includes the following categories: Sustainability, Resilience, Leadership, Commitment, Governance, Diversity and Adaptability.

The Green City Index (n.d.) has been developed by Siemens and features reports created for Europe, Asia, Latin America, North America, and Africa. The index focuses on environmental performance in urban environments, while accounting for geographical differences in its categories and indicators. For example, Africa's green city index does not state 'Buildings' as a category, but does include 'Sanitation' and 'Land Use.' The index has over 25 qualitative and quantitative indicators across multiple categories including CO_2 Emissions, Energy, Buildings, Transportation, Water, Waste and Land Use, Air Quality, and Environmental Governance. This index assists cities in developing intelligence through the accommodation of population growth and the promotion of economic opportunity, while also addressing the minimization of environmental footprints. An article by Citigroup (2012), describes a research program by the Economist Intelligence Unit (EIU) entitled 'Hotspots', designed to rank cities. The article also discusses the competitiveness of 120 major cities worldwide, via a "Global City Competitiveness Index". This index measures cities across eight distinct categories of competitiveness and 31 individual indicators. Categories include economic strength, human capital, institutional effectiveness, financial maturity, global appeal, physical capital, social and cultural character and environment and natural hazards. A city's overall ranking in the benchmark index is a weighted score of the underlying categories.

Based on the above studies, there are four primary themes which emerge from this "urban" landscape: (1) Technology, (2) Sustainability, (3) Economics and (4) Governance. Each of these have a set of attributes or examples as illustrated in Table 4.

Table 4. Common urban themes and associated attributes

Theme	Specific Attributes & Examples
Technology and Infrastructure	• Transportation - Road, Rail, Air • Buildings - Residential, Commercial, Industrial • Fire & Emergency Response • Healthcare • Urban Planning • Safety & Security • Education
Sustainability	• Energy - Consumption, Intensity, Renewables, Policy • Environment • Water - Consumption, Leakage • CO_2 - Emissions, Intensity, Reduction • Air Quality - NO_x, SO_x, Ozone, Particulates • Waste - Water, Solid, Landfills
Economics	• Economic Strength • Human Capital • Institutional Effectiveness • Financial Maturity • Physical (Financial) Capital • Production & Resourcing
Governance	• Organization & Administration • Law & Justice • Resilience • Leadership • Commitment

Sustainability and the Environment

With the increasing threat to humanity brought by climate change and global warming, smart cities must aim to make sustainability a cornerstone in their development and operation. Understanding environmental and sustainable indicators/indices in relation to an urban climate is crucial to develop an intelligent, sustainable city.

It should be noted that sustainability and the environment are sometimes used in the same context, although there is a clear distinction wherein the former is more holistic and includes the triple bottom line of economy, social (people / citizenry) and environment, whereas the latter applies more to our physical and biological surroundings. "Sustainability" applies to all human actions, such that current needs are met without hindering the ability to meet the needs of future generations, in terms of economic, environmental and social challenges. Environmental management as discussed on State of Green (n.d) seeks to ensure that the fabric of natural ecosystems are protected and maintained for the future, in terms of their ethical, economic and scientific (ecological) aspects. The reduction of carbon footprints is a major driver for almost all environmental initiatives. Such activity will protect the natural environment at individual, organizational or governmental level for the benefit of both the natural environment and people. The term sustainability is generally accepted to imply improving the quality of human life while living within the carrying capacity of the supporting eco-systems.

Researchers from Yale University, the European Union and CASBEE in Japan, have all provided a series of sustainability and environmental indicators in the urban, smart city context. These indicators shall be examined as a common set of attributes established as in the earlier analysis contained in this chapter. Esty et al. (2008) from Yale University have developed a list of over 25 environmental performance indicators for countries that aim to be more sustainable. It is instructive to consider which of the 25 variables recommended by Esty actually apply to an urban setting. Some of the more important variables include: Adequate Sanitation, Drinking Water Quality, Urban Particulates and Indoor Air Pollution, Ozone, Sulfur Dioxide (SO_2) Emissions and CO_2 Emissions Per Capita, and importantly represent the environmental burden of disease.

The European Union has been very proactive in defining urban sustainability through a variety of different initiatives. The Green Capital Index (n.d.) (GCI), instituted by the European Commission, has granted an award for urban sustainability to one city every year (since 2010). Multiple indicators are used to evaluate cities, including: the mitigation of, and adaptation to, climate change; transport; indoor and outdoor environmental quality (air, noise, pollution, water); waste management; energy efficiency; and nature / greenery.

Murakami et al. (2011) present CASBEE (Comprehensive Assessment System for Built Environment Efficiency) which serves as a framework with which to asses and rate the environmental performance of a built environment in Japan. CASBEE and its city version, CASBEE-CITY, are comparable to LEED in the United States and BREEAMS in the UK, as all of these use environmental efficiency as a foundation. CASBEE provides a comprehensive view of a city in relation to the Quality of Life and the Impact of Environmental Load. A city with low environmental load and high quality receives a high Built Environment Efficiency (BEE) rating, and is regarded as a sustainable city within the CASBEE framework.

Using the above studies as a basis for representing the key aspects of Sustainability and the Environment related to Smart Cities, the following natural themes and associated descriptions have been synthesized (Table 5). What is interesting to note is that some of the themes and descriptions overlap with those in the section on Urban

Table 5. Sustainability & environment related urban themes

Theme	Specific Attributes and Examples
City Infrastructure & Governance	• Policy and Management - Strategy, Administration, Conservation, Environmental Stewardship, Effective Conservation • Infrastructure - Urban Planning, Buildings & Physical Structures, Mobility & Transportation, Public Safety
Energy & Climate Change	• CO_2 from Energy Production • Emissions per Capita • Energy Efficiency & Management • Energy Conservation & Use of Renewables
Pollution and Waste	• Waste - Management, Treatment • Air - Air Quality, Particulates, Indoor Air Pollution, Ozone Levels, NO_x, SO_x • Water - Drinking, Water Quality, Water Stress, Management • Noise Pollution
Social, Economics & Health	• Social Services • Citizen Satisfaction • Education • Culture & Social Inclusion • Demographics (Aging) • Economics - GDP, Employment, Financial Resilience • Healthcare, Sanitation, Disease Control & Mitigation, Health Infrastructure & Services

Indicators and Quality of Life. The beginnings of an overarching set of indicators and attributes appear to be emerging. This will be discussed in more detail later on in the chapter.

Intelligence

Typically, Information and Communication Technology (ICT) denotes "intelligence", and is one of the most critical components of a smart city. However, the mere presence of ICT and high technology in a city in itself does not imply that it is an intelligent or smart city. ICT is more of an enabler, and if used properly and efficiently is indicative of the potential for making a city smart. More advanced ICT devices and services are critical to allowing intelligence to percolate down through a system.

ICT provides services that support urban living – security, healthcare, and transport for citizens, improved and more cost effective power supplies for industry, remote working and e-commerce for businesses, as well as entertainment and communications for individuals. ICT can also be used to monitor water, air, energy consumption and waste across sectors, and to improve accountability in the use of these resources. This helps mitigate the negative environmental effects of rapid urbanization.

This is best illustrated in the Climate Group (2008) report Smart 2020. Different ICT solutions are focused on, in an attempt to slow climate change. The ICT sector was found to potentially save up to 15% of global emissions in 2020, by enabling energy efficiency in base foundational infrastructure sectors. These include transport, energy, industry and buildings. A follow-up report, SMARTer 2020, by Gesi (2012), identified an additional 16% in energy savings by evaluating GHG abatement potential from ICT-enabled solutions ranging across six sectors of the economy: power, transportation, manufacturing, consumer and service, agriculture, and buildings.

Giffinger (2007), developed a system to better understand the concept of "smartness" in urban development in the case of medium-sized cities with a population of 100,000 to 500,000. In this context, 'smart' was defined as the implicit or explicit ambition of a city to improve its economic, social and environmental standards. Economy, People, Governance, Mobility, Environment and Living were identified as the key characteristics. The term "ICT" is contained within Mobility and Transport. A number of cities in Europe were ranked by Giffinger (2007) using this method. A smart city Evaluation Index has been suggested by Pan et al. (2011) based on the concept of leveraging ICT to improve city living. The index was developed within an Asian context for cities, most of which are in the process of developing. The following four (4) dimensions were used to describe the "smartness" of a city: (1) Smart Environment (2) Smart Business (3) Smart Citizens and (4) Smart Government.

Cohen (2012), a respected futurist, has developed a matrix of different indicators for smart sustainable cities based on a variety of existing indicators and indices such as the Mercer (2012) Index and the Green City Index. He has created a framework similar to that proposed by Giffinger (2007), giving equal weight to the key characteristics.

Tratz-Ryan et al. (2012), following Gartner, have proposed a framework for Smart Cities which comprises "Smart" (1) Buildings, (2) Public Services, (3) Education, (4) Utilities, (5) Healthcare and (6) Transportation. Bigliani (2011) from another major market research firm, IDC, has developed a Smart Cities Index, initially for Spain. Their aim is to address long-term sustainability using short-term initiatives, while convincing citizens to follow smart, sustainable lifestyles. Collectively, these have a strong positive impact on the economy and society, and they therefore improve the quality of life. There are two key dimensions to this index: (1) Enabling forces and (2) Smartness Dimension. Enabling Forces include the underlying characteristics of the city which facilitate or hinder its evolution into a smart city. These include People, Economy and ICT (Information and Communication Technologies). Smart dimensions are projects and policies put in place by the various city stakeholders such as: Government, Buildings, Mobility, Energy and Environment and Services – actions in the right direction for the future evolution of a smart city.

In summary, there is clearly a common set of themes which emerge from in this area of "smartness" for a city. Perhaps the most pragmatic way to look at "smartness" is by utilizing the following six (6) indicators (1) Mobility, (2) Economy, (3) Living, (4) Governance, (5) People and (6) Environment. It is implicit that there is an overarching ICT infrastructure which enables all these "smart" attributes to be realized.

Table 6 represents the above 6 indicators along with some of the key categories, as presented by a technical report from the ITU (2014) Focus Group on Smart Sustainable Cities. The following set of tables represent the key categories and some of the descriptors underlying each of them.

VIEW FROM THE ICT INDUSTRY[1]

An equally important view to consider is that of the ICT industry – since the ICT industry is what will make smart cities a reality, not only from a technological perspective but also in terms of a reality check on the economic viability of these very technologies. This view represents a "real world" scenario and provides a "sanity check" on the whole aspect of what a smart city is / can be / should be. This section provides the view of a smart city through the lens of the ICT industry. Such knowledge will help in developing a comprehensive definition of a smart city.

Several corporations worldwide, ranging from startups to multinationals, have begun planning and implementing strategic, ambitious solutions and programs relating to sustainability and smart cities. A lot of these companies focus on specific verticals such as buildings (real estate), energy (sustainability), transportation (mobility), utilities (grid, electricity, gas, water) healthcare, education, government, and so on. Many companies that have ventured into the smart cityscape base their research and projects on a core foundation of ICT. They are best poised to take advantage of the different parts of the ICT value chain, ranging from sensors to hardware, middleware to software and appropriate end use applications to provide holistic solutions. Some ICT companies try to give an overview of, and provide a visionary solution for, smart cities.

We shall focus on the following three types of ICT-centric industry: (1) Telecom Service Providers, (2) Networking and Communications companies, and finally (3) companies with Enter-

Table 6. Six primary indicators for a "smart" city

Smart Mobility	Smart Economy	Smart Living
• Accessibility • Safe Transportation • Innovative Technologies • Increased efficieny and intelligence across transportation systems • Leverage for networks providing efficient movement of vehicles, people, and goods (therefore reducing gridlock) • Changing societal attitudes towards activities such as car sharing, car pooling, and car-bike combinations	• Regional/global competitiveness • Entrepreunership & Innovation Momentum • High Levels of Productivity • Increased broadband access for all citizens and businesses, improving opportunities • Sustainance of business independent of location, maintaining rural populations. • Electronic business processes (e.g., e-banking, e-shopping, e-auction)	• High Quality of Life • Social Aspects - Education, healthcare, Public Safety, Housing • Access to high-quality healthcare services such as e-health or remote healthcare monitoring • Providing electronic health records management • Home automation, smart home and smart building services • Access to social services

Smart Governance	Smart People	Smart Environment
• Decision Making • Public & Social Services • Transparency • Increased democraticization and political efficacy • Interconnecting governmental organizations and administrations • Enhanced community access to a multitude of services	• Social & Human Capital • Qualified, Creative and Educated Citizenry • Able to utilize the ICT based smart services • Consistent educational experiences across urban and rural regions • E-education solutions including remote learning and collaboration, better informing citizens	• Pollution Monitoring • Use of Sustainable Technologies • Environmental sustainability and reduced energy usage • New technological innovations that promote energy conservation and material re-use, in turn reducing energy consumption

prise solutions. Some of the activities and efforts in regards to smart cities by these three industry verticals will be presented and some conclusions drawn to establish this view of what a smart city is or should be.

Telecommunications Service Providers (Telcos)

Telcos are among the leading contenders to provide services for smart and sustainable cities. The companies are well suited to providing value added services. Many of them have gone far beyond their traditional telephony businesses into internet, media and even entertainment (television), and are also involved in other infrastructural and logistical activities that are already well established. Smart city services therefore represent a natural next step.

In a report entitled Connected Living (2014), the GSM Association (GSMA) program offers an approach designed to accelerate the development of an 'intelligently connected world'. The program aims to assist telecom (mobile) operators accelerate the usage of wireless connectivity through a wide range of devices and services. In response to the advent of smart cities, focus areas for value added services now include health, the automotive industry, education, and utilities where operators provide more than network connectivity. In addition they also have a specialized program called 'Mobile Connected" to enable smart cities through mobile phone applications. The primary aspects that the GSMA believes to be of critical importance include: (1) Smart Mobile Services, (2) Mobile Infrastructure, (3) Smart Citizens and (4) the convergence of Mobile technologies with Business and Economics.

Telefonica (n.d) is a major Telco that the Carbon Disclosure Project (CDP) ranks highly, as "a leading telecommunication enterprise in energy efficiency services in Europe and Latin America". SmartCity-Telefonica is a group within Telefonica that has developed a smart cities framework model based on connectivity, energy efficiency and dematerialization. The group has deployed ICT in Spain to create the smart cities of Santander and Malaga. The smart city project running in Santander has over 12,000 sensors citywide designed to improve public services and increase their efficiency, in regard to mobility, energy, environment, open government, security and communication. Malaga focuses on energy, renewable energy production, smart metering, lighting and automation.

Berst (2013) describes AT&T's "Smart City Concepts" which increase efficiency while trying to reduce costs. The company employs a variety of critical services – connectivity, security, payment, location-based services – to enhance urban intelligence. AT&T brings in the technology to a foundational mobile platform and connects all the endpoints to the platform. Through such an approach, AT&T improves employee productivity, citizen engagement and solutions in areas like energy, water, safety and security, transportation and economic development. AT&T is also participating in niche solutions and special programs such as "Smart Santander", described by Enbysk (2013).

With the aim of optimizing city services, Taft (2013) and Sahota (2013) describe how Deutsche Telekom and IBM have partnered to create holistic solutions. These combine IBM's huge database of cities with the Machine-to-Machine services offered by Deutsche Telekom, facilitating integration, advanced network connectivity, and the automatic interchange of information between monitoring machines. Telecom Italia (2013) has different solutions in place to reduce CO_2 emissions and energy consumption, and improve citizens' quality of life. Telecom Italia aims to improve infrastructure, guarantee better health information management and make mobility and transportation more efficient.

To summarize, Telcos view smart cities as having highly connected ICT infrastructure through which information flows to improve healthcare, education, energy (smart grid), and transport. The intent is to empower citizens so that they may access information about anything anywhere on any device, especially those of a mobile variety. A new generation of applications will be introduced in smart cities to combine various kinds of information about the city and supply it to residents. All of this will ostensibly lead to an improved standard of life for its citizens.

Networking and Communications Companies

Networking and Communications companies provide the backbone of technology and ICT infrastructure and hence have a strong interest in a smart city. This backbone is what the city will run on in terms of data communications and transfer of information. Companies such as Ericsson, Cisco, NTT, Schneider Electric, Siemens and Huawei are just a few examples of companies that are keen on developing and operating smart cities.

Ericsson's "Networked Society" concept (2012 and 2014) is a vision of a futuristic, ultra-connected society. The project is the basis for a framework tool that measures and assesses a city's ICT maturity, in terms of investment, network penetration, performance and the resulting triple-bottom line (social, economic and environmental) benefits. The networked society city index has three aspects: (1) city, (2) citizen and (3) business.

Aoun (n.d.) from Schneider Electric states that a smart city must be livable (deliver benefits to all key stakeholders), efficient (cost effective and compliant with regulations) and sustainable (respect for the past while preparing for the future). Public governance, people ownership, and business cooperation is also important to the city's survival. Schneider Electric (2014) states that a smart city can be considered to be a system of systems revolving around 5 key themes with a central "Integration Platform" to bring all under a common operating paradigm. These principal themes are (1) Smart Energy, (2) Smart Water, (3) Smart Mobility, (4) Smart Public Services and (5) Smart Buildings.

Cisco Systems boasts several projects in this area of Smart Cities. These include the Cisco Smart Connected Communities (n.d.), (S+CC), Cisco (n.d.) Connected Urban Development (CUD) as described by Villa and Wagener (2008), and recently the Cisco (n.d.) "Internet of Everything" initiative. The Cisco S+CC project focuses on three key drivers: Social, Environmental and Economic; and as such it brings together a broad portfolio of partnerships, products, services, and solutions to address urban intelligence. S+CC is a framework within which quality of life is improved by connecting the device-information systems as well as people together in an intelligent and contextual way. CUD is a decision supporting tool that demonstrates the reduction of carbon emissions through efficient, ICT employing urban infrastructure. A recently developed toolkit includes smart work, travel assistance, urban energy and mobility, along with an associated framework. Cisco has now launched an "*Internet of Everything*" project. Cisco defines the Internet of Everything (IoE) as "bringing together people, process, data, and things to make networked connections more relevant and valuable than ever before-turning information into actions that create new capabilities, richer experiences, and unprecedented economic opportunity for businesses, individuals, and countries".

Siemens (n.d.) has created a corporate group called "Cities and Infrastructure". In addition to being a primary driver of the Green City Index discussed earlier in this report, they have "smart solutions for smart cities". Areas covered are primarily infrastructure based and include Lighting, e-Mobility, Energy Efficient Buildings, Smart Grid, Industries, Transport and Renewable Energies. Siemens has solutions for harbors, airports, water, energy, public administration, financing, sports venues, security, buildings, transport, and health care. NTT (2013), in a joint paper with Fujitsu, presents a concept for a smart city (SSC). They propose that addressing basic physical and ICT infrastructure, in relation to energy, transport, water, waste, medical care, administration, education, environmental issues, urban revitalization, disaster prevention, and citizens' wellbeing, is the key to sustainable development. According to Huawei (n.d.), a smart city should be able to efficiently handle the plethora of data resulting from the information boom. Digital and physical infrastructure will converge and the intelligent functions powered by network and IT technologies will enable citizens of a smart city to improve their quality of life.

A common theme across all of the networking companies is that all of them are applying networking and communications technologies to a list of physical infrastructure verticals. The typical verticals which are being addressed include: Energy Management, Building Management, Transportation & Mobility, Waste Management, Water Management, Healthcare, Education and Physical Safety & Security. Each of these infrastructural elements in turn has a host of detailed descriptors and characteristics which need to be considered.

Enterprise Companies

IBM Smarter Planet (n.d.) is a corporate initiative from IBM that highlights the potential that smarter systems have to achieve efficient, sustainable economic growth for society at large. This "system of systems" includes the management of water, smart grids, buildings, and traffic. Traditionally, each of these systems has been difficult to analyze and manage, due to its size and complexity. IBM's strategy, however, is to provide or enable many of these technology and process management capabilities to resolve these problems using data analytics.

Toshiba (n.d.) boasts the concept of the "smart community" – the next generation community – in which the management and control of various infrastructures (electricity, transportation, logistics, medicine, information) is optimized. In relation to the smart community, Toshiba has been developing comprehensive solutions encompassing energy, water, and medical systems in order to realize a synergetic balance between environmental consideration and comfortable living. The different solutions can be divided into vertical infrastructural elements including: Energy, Water, Information, Transport and Medical care. Fujitsu (2014) has a vision of an ICT-driven smart city. Their stated goal is "Promoting environmentally conscious cities to balance environmental stewardship with comfortable living (including the infrastructure) in the world".

Symantec (2014) discusses the need for cyber security and associated resilience. Cities access a lot of information through the ICT system. More information means more knowledge and therefore the increased vulnerability of data security. The more complex a system, the greater the need for cities to protect such data. Symantec believes that smart cities would definitely thrive and prosper if cyber security and information protection were fundamental components of the services provided to constituents. Population growth, economic crises, resource crises, growing energy demands, the need for regulatory compliance, the urgent need for carbon emission targets, the increasing importance of public safety, security and exposure to online data transmission, are forcing cities to become smarter.

SAP (2014) recently launched an "Urban Matters" program. This initiative is designed to help urban centers develop more effective government and better management. In consideration of business-citizen transactions, Oracle (2011) has set up a Solution for Smart Cities program. The group recognizes the need for the transparent, efficient, intelligent interaction of people, local authorities and businesses, especially for tasks like information requests, incident reporting, inspection scheduling and completing the online start-up of local businesses. It is part of the iGovernment initiative which addresses the needs of the Public Sector with regard to ICT (Information, Computers and Telecommunications).

Mlot (2013) describes the Microsoft City Next program to be a global initiative intended to build "smart cities" around the world using cloud technology, mobile devices, data analytics and social networks. These will help cities improve their economies, in spite of issues with rapid urbanization and budgetary constraints. It aims to develop an era of cooperative technology designed to engage citizens, business and government leaders in new and innovative approaches. For example, by enabling critical information to flow seamlessly between government, businesses and citizens, society at large will likely be better prepared for major emergencies (a case in point is Hurricane Sandy, which devastated the eastern seaboard of the United States). City Next aims to connect functions like energy, water, infrastructure, transportation, public safety, tourism, recreation, education, health and social services, and government administrations.

Once again, very much like the Telcos and the networking companies, enterprise companies are all looking at infrastructure and associated applications related to those verticals, as what will make a city "smart". The emphasis appears to be on how to connect and develop "bridges" across these verticals which are normally siloed and do not "talk to one another". Examples include e-governance, data security, big data, data analytics and the "internet of things".

Summarizing Industry's View

Looking at the different industry's viewpoints of the smart city, it is clear that the focus is on "Infrastructure and Services". While most of the companies are in the ICT space, their view is that ICT will provide the overarching integrating function for (1) the different physical infrastructure such as buildings, roads, factories, power generation and the like, and (2) the ability to deliver smart services. Both of these areas provide tangible economic benefits to the industrial players at large. Finally there is the ICT or digital and software layer which acts as a "glue" uniting the various verticals to help optimize the different aspects of a city as a whole.

Once industry starts to develop products and solutions in this space, one of the key aspects is the standardization of terminology, the interoperability across different systems and approaches. This is typically driven by a standards approach and governed by standards organizations such as the ITU and the ISO, among others. The next section shall consider the view of Standards Developing Organizations SDOs, and will therefore round off the overall, 360^{o} viewpoints being gathered – before bringing all the different aspects together into a comprehensive summary.

INTERNATIONAL STANDARDS EFFORTS

As a given industry segment such as smart cities starts to evolve and mature, it is essential that a common ground, or set of standards, is established. This aims to start bringing together the various aspects of the analysis developed in this chapter on what constitutes a smart city, by establishing the uniformity of the global phenomena of smart cities.

Rules, guidelines and standards are created by means of a consensual approach. These typically include regulations, guidelines, best practices, specifications, test methods, design or installation procedures and the like. Applying standards within a smart city context can be quite complicated, especially since cities have complex, interconnected systems across a variety of different verticals such as buildings, transportation, health, education, public safety, energy, water, waste and telecommunications.

Standards are important for a number of reasons:

- Standards form a key foundation for such an urban infrastructure across all vertical sectors.
- Standards can act as a foundation to make cities smarter, more sustainable and more resilient.
- Standards are at the heart of innovation in "smart" information and communications technologies. Examples include smart sensor and data networks which collect, transmit and analyze data in order to help cities be more efficient in delivering services to their citizens.
- Standardized efforts to improve green buildings, energy efficiency and climate change mitigation enhance the quality of life and the environment, both of which are beneficial for the urban populace.

Standards Development Organizations (SDOs) develop and specify standards for initiatives, including smart city programs. UNEP, UN-HABITAT and the World Bank have drafted a standard for cities reporting of GHG emissions. Other standards organizations such as the IEEE, ANSI, ETSI, ETNO, CENELEC, CCSA, DIN/DKE, GIFSI, IEC and TIA are also working on smart, sustainable cities. While the smart cities concept is fairly new, several corporations and organizations recognize its importance.

Some of the more proactive standardization projects (to date) relating to smart sustainable cities include:

- International Telecommunication Union (ITU): an on-going standardization undertaking related to the environmental assessment of cities
- British Standards Institution (BSI): this recently launched a smart city standards initiative
- International Standards Organization (ISO): this has launched a project concerning smart community infrastructures.

International Telecommunications Union (ITU)

The ITU-T is the technology arm of the International Telecommunications Union (ITU), a specialized agency of the United Nations focusing on information and communication technology. The ITU (2013) established a focus group in February 2013 to study Smart Sustainable Cities under the auspices of Study Group 5 (SG5). A series of open meetings have been organized with stakeholders from Telcos, ICT companies, governments, and broad-based information platforms have been provided. This is helpful in sharing views, developing deliverables, show-casing initiatives, projects, policies and standards activities. The group also analyzes ICT solutions/projects promoting sustainability, and identifies best practices that facilitate implementation in cities. In conjunction with other SDOs and forums' activities, it will soon develop a standardization roadmap for major smart city initiatives.

Some of the focus group's key activities include:

- Establishing liaisons and relationships with other organizations which could contribute to the standardization activities of ICTs, environment and climate change in cities.
- Publishing a roadmap of the ICT sector's contribution to smart and sustainable cities.
- Suggesting future ITU-T study items and related actions within the scope of the ITU-T SG5 (see Appendix) for example on:
    - Concepts, coverage, vision and use-cases of smart and sustainable cities.
    - Characteristics and requirements of smart and sustainable cities.
    - Efficient services and network infrastructure of smart and sustainable cities, as well as their architectural framework from the environmental impact point of view.
- Identifying or developing a set of key performance indicators (KPIs) to assess how the use of ICTs impacts the environmental sustainability of cities.
- Fostering the development of strategies and best practices relating to policies and standards to help cities deliver ICT environmental services, including the optimization of the use of scarce resources and the building of resilience to climate change in cities.
- Identifying and finding ways to overcome potential barriers in the use of ICTs to achieve environmental sustainability in cities.

A series of technical reports and deliverables ranging from definitions, KPIs and benchmarks, infrastructure, smart buildings among others are in progress and are expected to be available within the next 12 months.

British Standards Institution (BSI)

The British Standards Institution (n.d.) (BSI) has developed a Smart Cities Standards Strategy to address the complex issue of sustainability and technology as it applies to smart cities. The advantages of considering a city holistically, far outweigh those of individual smart services when looked at in isolation. The report "A Standards Strategy for Smart Cities", based on collective input from citizens, ICT companies, government, research and academia, states that a smart city is multi-faceted and complex, with several stakeholders and attributes. Thus, there is a need for the introduction of guidelines and technical specifications. Such metrics facilitate the seamless collaboration of governments, citizens and the private sector. The three axes along which the strategy has been developed are: (1) Vertical Sector Infrastructure, (2) Services Infrastructure and (3) Management Infrastructure.

International Standards Organization (ISO)

The International Organization for Standardization (2014), commonly known as ISO, has been proactive in the area of Smart Cities and Communities. Several different proposals fall within ISO's aim to develop standards relating to global city indicators and sustainable development in communities. ISO has also reviewed existing activities pertaining to the metrics for smart community infrastructures, and has issued a report entitled *Sustainable development of communities -- Indicators for city services and quality of life* (International Organization for Standardization, 2014). The approach taken by ISO is based on (1) Intelligence, (2) Infrastructure and (3) Community. The study covers key components of urban infrastructure, such as energy, water, transportation, waste and information and communications technology (ICT). Technical aspects which have been published, implemented or presented are discussed. The concept of smartness or intelligence as applied to technologies and implementable solution is addressed in terms of performance, with sustainability and the community's resilience as a backdrop.

Summary of the SDO Viewpoints

The following conclusions have been drawn up based on the ongoing work at SDOs: looking at single or point solutions for cities may not really be "smart", but considering multiple aspects and issues is essential. There needs to be a strong focus on the interoperability and efficiency of urban operations.

Energy, Water, Transportation, Waste and ICT are key infrastructural elements. The quality of life is also a key consideration. A smart city should have benchmarks and key performance indicators to ensure that the urban environment follows a tangible path and process towards intelligence.

PUTTING IT ALL TOGETHER: A COMPREHENSIVE VIEW

This study has thus far considered a variety of indicators, industry's view, standards projects and a set of definitions for a smart city. The information has been obtained from many different sources and stakeholders, providing a holistic approach to the definition of the smart city. As can be observed, the different viewpoints discussed so far all focus on a variety of key terms and topics, all of which are relevant to a smart city. There are clearly certain overlaps which emerge as the truly pivotal aspects of a smart city.

So, what constitutes a "smart city"? The answer appears to lie in a combination of the following three aspects, which appear of pivotal importance when describing a smart city:

- Themes of Society, Economy, Environment and Governance
- Different types of infrastructure – Physical, Service and Digital
- A recurring set of terms and keywords which characterize a smart city.

Combining the Themes, Infrastructure and Key Words, we are able to coalesce and identify what really constitutes a smart city.

Common Themes

According to the technical reports from ITU (2014) four themes emerge for a smart city (with infra-structure as a foundation) as detailed in Table 7:

- Society: the city is for its inhabitants (the citizens)
- Economy: the city must be able to thrive – jobs, growth, finance
- Environment: the city must be sustainable in its functioning for future generations
- Governance: the city must be robust in its ability to administrate policies and bring together the different elements.

Infrastructural Verticals for a smart city

Three distinct types of infrastructure in a city become apparent: (1) physical, (2) service and (3) digital.

1. Physical infrastructure is what we can touch and feel, for example, buildings (all types – homes, offices, hospitals and similar), roads, physical transport (trains, buses, cars), and utilities (electricity, gas, water).
2. Service infrastructure consists in the provi-sion and supply of electricity, the provision of education, healthcare, mass rapid transport, mobile / cellular systems

Table 7. Economy, governance, environment and societal themes in a smart city

Economy	Governance	Environment	Society
• Employment	• Regulatory	• Sustainable	• People
• GDP	• Compliance	• Renewable	• Culture
• Market – Global	• Processes	• Land Use	• Social Networks
• Viability	• Structure	• Bio-Diversity	• Tech Savvy
• Investment	• Authority	• Water / Air	• Demographics
• PPP	• Transparency	• Waste	• Quality of Life
• Value Chain	• Communication	• Workplace	• User Experiences
• Risk	• Dialog		• Equal Access
• Productivity	• Policies		• End Consumers
• Innovation	• Standards		• Community Needs
• Compensation	• Citizen Services		• The City as a Database

3. Digital infrastructure includes the backbone for communications, internet, mobile network, data, cloud computing, the internet of things.

One should think of the physical infrastructure as the core foundation upon which the services infrastructure rides and provides distinct and siloed services in specific verticals. The Digital infrastructure then provides an ICT – an integration layer allowing for cross pollination of these services, perhaps in the form of converged applications, bringing different people together. One simple example is alerting transportation networks of a flood situation in a given part of the city, in real time, so as to allow for the re-routing of traffic.

When all of these forms of infrastructure combine and converge, a smart city begins to take shape.

Keyword / Terms

Based on the extensive and methodical analysis conducted by the author as part of the ITU (2014) Focus Group on Smart Sustainable Cities, it was found that there is a recurrent set of key words / terms. This leads the authors to believe that the following 30 key terms / words are highly relevant and must be considered when describing a smart city.

1. ICT
2. Adaptable
3. Reliable
4. Scalable
5. Accessible
6. Security
7. Safe
8. Resilient
9. Economic
10. Growth
11. Standard of Living
12. Employment
13. Citizens
14. Well Being
15. Medical
16. Welfare
17. Physical Safety
18. Education
19. Environmental
20. Transportation & Mobility
21. Physical & Services Infrastructure
22. Water
23. Utilities & Energy
24. Telecommunications
25. Manufacturing
26. Natural/Man Made Disasters
27. Regulatory & Compliance
28. Governance
29. Policies & Processes
30. Standardized

PROPOSED COMPREHENSIVE DEFINITION

Based on the research and discussion presented in this chapter, the authors propose a comprehensive definition which attempts to incorporate as many of the different aspects as possible. We recognize that the specific "lens" through which a smart city is viewed will definitely vary and there will be many proposed definitions that will all be true within their own dimension.

The following comprehensive definition is proposed as one of the many possibilities:

A smart city uses the ICT (digital) infrastructure as a foundational platform using an adaptable, reliable, scalable, accessible, secure, safe and resilient approach in order to:

- *Preserve and Improve the Quality of Life of its Citizens.*
- *Create an environment for tangible economic growth including a higher standard of living and employment for its citizens.*

- *Address the well-being of society, through the provision of medical care, welfare, physical safety and education.*
- *Develop and implement an environmentally responsible and sustainable policy framework that "meets the needs of today without sacrificing the needs of future generations".*
- *Optimize physical and services infrastructure such as transportation (mobility), water, utilities (energy), telecommunications, and manufacturing.*
- *Consider solutions for natural and man-made disasters, including the effects of climate change.*
- *Establish effective and well-balanced governance (including regulatory and compliance) mechanisms and processes in an equitable and standardized manner.*

REFERENCES

Aoun, C. (n.d.). *The smart city Cornerstone: Urban Efficiency*. Schneider Electric. Retrieved June 16, 2014, from http://www.digital21.gov.hk/eng/relatedDoc/download/2013/079%20SchneiderElectric%20(Annex).pdf

Azkuna, I. (n.d.). *Smart Cities: International study on the situation of ICT, innovation and Knowledge in cities.* Retrieved June 16, 2014, from http://www.cities-localgovernments.org/committees/cdc/Upload/formations/smartcitiesstudy_en.pdf

Berst, J. (2013). *AT&T's smart city Solutions: Q&A with Reed Pangborn*. Retrieved June 16, 2014, from http://smartcitiescouncil.com/resources/atts-smart-city-solutions-qa-reed-pangborn

Bigliani, R. (2011). *Smart Cities Update: IDC Smart Cities Index and Its Application in Spain*. International Data Corporation.

BSI. (n.d.). *Smart Cities*. Retrieved June 16, 2014, from http://shop.bsigroup.com/en/Browse-By-Subject/Smart-Cities/?t=r

Caltrans. (2010). *Smart Mobility 2010*. Caltrans. Retrieved June 16, 2014 from http://www.dot.ca.gov/hq/tpp/offices/ocp/smf_files/Planning_Horizons_Presentation_070710/Intro_SMF_Chris_Ratekin_Plng_Hrzns_070710.pdf

Cisco. (n.d.). *CUD Thought Leadership - Cisco Consulting Thought Leadership*. Retrieved June 16, 2014, from http://www.cisco.com/web/about/ac79/ps/cud/thought_leadership.html

Cisco. (n.d.). *Internet of Everything*. Retrieved June 16, 2014, from http://www.cisco.com/web/about/ac79/innov/IoE.html

Cisco. (n.d.). *Smart+Connected Communities - Industry Solutions*. Retrieved June 16, 2014, from http://www.cisco.com/web/strategy/smart_connected_communities.html

Citigroup. (2012). *Benchmarking global city competitiveness*. The Economist. Retrieved June 16, 2014, from http://www.citigroup.com/citi/citiforcities/pdfs/eiu_hotspots_2012.pdf

City Indicators. (n.d.). *Global City Indicator Facility (GCIF) Indicators*. Retrieved June 15, 2014, from http://www.cityindicators.org

Cohen, B. (2012). *What Exactly is A smart city?* Retrieved June 16, 2014, from http://www.fastcoexist.com/1680538/what-exactly-is-a-smart-city

Connected Living. (2014). *Smart Cities*. Retrieved June 16, 2014, from http://smartcitiesindex.gsma.com/indicators/

Economist. (2004). *The Economist Intelligence Unit's quality-of-life index*. The Economist. Retrieved June 16, 2014, from http://www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf

Enbysk, L. (2013). *Smart cities: Why it's location, location (and communication)*. Retrieved June 16, 2014, from http://smartcitiescouncil.com/article/smart-cities-why-its-location-location-and-communication

Ericsson. (2012). *Networked Society: Triple-bottom-line effects of accelerated ICT maturity in cities worldwide*. Retrieved June 16, 2014, from http://www.ericsson.com/res/docs/2012/networked-society-city-index-report-part-1.pdf and from http://www.ericsson.com/res/docs/2012/networked-society-city-index-report-part-2.pdf

Ericsson. (2014). *Networked Society*. Retrieved June 16, 2014, from http://www.ericsson.com/thinkingahead/networked_society

Esty, D., Kim, C., Srebotnjak, T., Levy, M., Sherbinin, A., & Mara, V. (2008). *2008 Environmental Performance Index*. New Haven: Yale Center for Environmental Law and Policy.

Fujitsu. (2014). *smart city*. Retrieved June 16, 2014, from http://jp.fujitsu.com/about/csr/feature/2012/smartcity/

Gesi. (2012). *SMARTer2020*. Retrieved June 16, 2014, from http://gesi.org/SMARTer2020

Giffinger, R. (2007). *Smart cities Ranking of European medium-sized cities*. Vienna, UT: Centre of Regional Science.

Global Compact. (n.d.). *The Cities Programme*. Retrieved June 15, 2014, from http://citiesprogramme.com

Government of Ireland. (2008). *Building Ireland's Smart Economy. A Framework for Sustainable Economic Renewal*. Dublin. Green Capital Index. (n.d). *European Green Capital: Evaluation Process*. Retrieved June 15, 2014, from http://ec.europa.eu/environment/europeangreencapital/applying-for-the-award/evaluation-process/index.html#sthash.QXukMUww.dpuf

Green City Index. (n.d.). Retrieved June 16, 2014, from www.siemens.com/entry/cc/en/greencity-index.htm

Huawei (n.d.). *Brilliant life powered by smart city.docx*. Retrieved June 16, 2014, from http://www.huawei.com/en/about-huawei/publications/communicate/hw-079367.htm

IBM. (n.d.). *IBM Smarter Planet*. Retrieved June 16, 2014, from http://www.ibm.com/smarter-planet/

International Organization for Standardization. (2014). *Sustainable development of communities -- Indicators for city services and quality of life*. International Organization For Standardization.

ITU. (2012). *Toolkit on environmental sustainability for the ICT sector*. ITU-T.

ITU. (2013). *Focus Group on Smart Sustainable Cities*. Retrieved from http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

ITU. (2014). *Smart Sustainable Cities: An Analysis of Definitions*. Retrieved from http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

Mercer. (2012). *2012 Quality of Living Survey*. Mercer. Retrieved June 16, 2014, from http://www.mercer.com/newsroom/2014-quality-of-living-survey.html

Mlot, S. (2013). *Microsoft City Next Aims to Build 'Smart Cities'*. Retrieved June 16, 2014, from http://www.pcmag.com/article2/0,2817,2421635,00.asp

Murakami, S., Asamai, Y., Ikaga, T., Yamaguchi, N., & Kaburagi, S. (2011). Development of comprehensive city assessment tool: CASBEE-City. *Building Research and Information*, *39*(3), 195–210. doi:10.1080/09613218.2011.563920

Nokia Solutions and Networks. (n.d.). *The ICT behind cities of the future*. Retrieved June 16, 2014, from http://nsn.com/news-events/publications/unite-magazine-february-2010/the-ict-behind-cities-of-the-future

NTT. (2013). *Vision of a Smart Sustainable City*. Retrieved June 15, 2014 from http://ifa.itu.int/t/fg/ssc/docs/1309-Madrid/in/fg-ssc-0035-japan_NTT_fujitsu.doc

Oracle. (2011). *Oracle's Solutions for Smart Cities: Delivering 21st Century Services*. Oracle. Retrieved June 16, 2014 from http://www.oracle.com/us/industries/public-sector/032422.pdf

Pan, J. G., Lin, Y.-F., Chuang, S.-Y., & Kao, Y.-C. (2011). From governance to service-smart city evaluations in Taiwan. In *Proceedings of International Joint Conference on Service Sciences* (pp. 334-337). doi:10.1109/IJCSS.2011.74

Sahota, D. (2013). *Deutsche Telekom partners with IBM for Smarter Cities*. Retrieved June 16, 2014, from http://www.telecoms.com/108942/deutsche-telekom-partners-with-ibm-for-smarter-cities/

SAP. (2014). *SAP for Public Sector - SAP for State & Local Government*. Retrieved June 16, 2014, from http://global.sap.com/campaigns/2012_08_public_services/state_local_overview.epx

Schneider-electric. (2014). *Smart Cities*. Retrieved June 16, 2014, from http://www.schneider-electric.com/sites/corporate/en/solutions/sustainable_solutions/smart-cities.page

Siemens. (n.d). *Infrastructure & Cities - Sustainable Cities*. Retrieved June 16, 2014, from http://w3.siemens.com/topics/global/en/sustainable-cities/Pages/home.aspx

Smart Governance Network. (n.d.). Retrieved June 16, 2014, from http://www.smartgovernance.net/smartdynamic/dynamic_default.asp?id=1

State of Green. (n.d.). *Smart Energy City, Copenhagen*. Retrieved June 16, 2014, from https://stateofgreen.com/en/profiles/ramboll/solutions/smart-cities-1

Sullivan, A., & Sheffrin, S. M. (2003). *Economics: Principles in action*. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Symantec. (2014). *Transformational 'smart cities': cyber security and resilience*. Symantec. Retrieved June 16, 2014 from https://eu-smartcities.eu/sites/all/files/blog/files/Transformational%20Smart%20Cities%20-%20Symantec%20Executive%20Report.pdf

Taft, D. (2013). *IBM, Deutsche Telekom Team on Smarter Cities Effort*. Retrieved June 16, 2014, from http://www.eweek.com/enterprise-apps/ibm-deutsche-telekom-team-on-smarter-cities-effort/

Telecom Italia Corporate. (2013). *Socio-environmental telecommunications solutions*. Retrieved June 16, 2014, from http://www.telecomitalia.com/tit/en/innovation/hot-topics/scenarios/smart-services.html

Telefonica. (n.d.). *Sustainability*. Retrieved June 16, 2014, from http://www.crandsustainability.telefonica.com/en

The Climate Group. (2008). *Smart 2020*. Global e-Sustainability Initiative. Retrieved June 16, 2014 from http://www.smart2020.org/_assets/files/02_smart2020Report.pdf

Toshiba. (n.d.). *Smart Community*. Retrieved June 16, 2014, from http://www.toshiba-smartcommunity.com/EN/

Tratz-Ryan, B., Di Maio, A., Velosa, A., & Nakano, N. (2012). *Innovation Insight: smart city Aligns Technology Innovation and Citizen Inclusion*. Gartner Inc. Retrieved June 16, 2014 from https://www.gartner.com/doc/2286119/innovation-insight-smart-city-aligns

Tsuda, M., Hara, M., Nemoto, Y., & Nakamura, J. (2007). Gross Social Feel-good Index – Social Impact Assessment for ICT Services. *NTT Technical Review*, *5*(3). Retrieved from https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200703043.pdf

United Nations. (2013). *World Economic and Social Survey 2013, Sustainable Development Challenges*. Retrieved June 16, 2014 from https://sustainabledevelopment.un.org/content/documents/2843WESS2013.pdf

Villa, N., & Wagener, W. (2008). Connecting Cities: Achieving Sustainability through Innovation – an overview of the connected urban development program. *In Proceedings of CISCO's Connected Urban Development Global Conference*.

World Health Organization. (1997). *Measuring Quality of Life*. World Health Organization. Retrieved June 16, 2014 from http://www.who.int/mental_health/media/68.pdf

KEY TERMS AND DEFINITIONS

City: An urban environment with a large population and possibly a high population density.

Definition: A concise description or specification of the attributes and characteristics of what is being defined, such that it can be used as a benchmark or to uniquely identify it.

Economy: Financial and Societal aspects related to the production, distribution or trade, and consumption of goods and services (including ICT, Energy).

Governance: Establishing and executing against a strategic direction related to society, the manner in which public services are delivered, while managing risks and ensuring compliance with regulatory and policy requirement. In a Smart City, this includes e-government and using ICT to facilitate and support better planning and decision making.

ICT: Information and Communications Technologies not limited to Voice, Video Data, PCs or Smart Phones but incorporating the Internet of Things, Sensors, Analytics and Big Data.

Infrastructure: Infrastructure refers to a set of interconnected structural and organizational elements (physical-physical, service-service and service-physical) that provide the framework to support an economy. There are two types of infrastructure - physical (examples: Buildings, Roads, Utilities) and services (examples: education, and healthcare).

Smart: A state of intelligence as applied to technologies and implementable solutions in relation to optimized performance levels without compromising sustainability and community (human) related aspects.

Society: People (humans) who live, work and play together harmoniously especially in terms of social and cultural interaction. In a smart city context, such interaction has a technological component with a goal to help improve the quality of life.

Sustainability: An umbrella term for all human activity designed to meet current needs without hindering the ability to meet the needs of future generations in terms of economic, environmental and social challenges.

ENDNOTE

1 This section presents only a representative view of the Smart Sustainable City activities and viewpoints of the private sector. It is by no means intended to be an all-inclusive listing. It is not a reflection that companies listed are the only ones doing work in smart cities or an indication that one company is ahead of another. It is only intended to validate that the activity and solutions around Smart Cities are indeed real and thereby giving credibility to the view that "smart cities have arrived".

Chapter 2
Smart Cities and the Internet:
From Mode 2 to Triple Helix Accounts of their Evolution

Mark Deakin
Edinburgh Napier University, UK

ABSTRACT

This chapter challenges recent mode 2 accounts of smart cities and in particular, the idea they are an index of the future internet. Adopting the triple helix model of knowledge production, it studies smart cities, not as the emergent technologies of economic transactions, but in terms of civil society's support for the integration of Web2.0-based information and communication platforms into their regional innovation systems. This reveals that no matter how technologically advanced such an internet-driven reinvention of cities may appear, being smart is something which reaches beyond this. Beyond this and towards policies, leadership qualities and corporate strategies that not only serve the knowledge economy, but which are also smart in allowing cities to cultivate the creativity of the internet as the information and communication technologies of regional innovation systems.

INTRODUCTION

Over the past decade, cities have increasingly become the object of academic interest, scientific and technical study. Examples of this appear in the work of Landry (2008), Komninos (2008) and Hollands (2008) on the innovation of creative, intelligent and smart cities. Collectively they serve to highlight some of the most pressing socio-demographic issues currently facing the scientific and technical community: the need for cities to be(come) innovative hubs and creative milieus and requirement for their institutions to not only be intelligent, but smart. Together they also do much to map out the institutional setting for the scientific and technical community to begin learning about the knowledge base of smart city developments. Separately they also offer a series of critical insights into how little the scientific and technical community currently knows about either the innovation, or creativity underpinning such developments, let alone the basis of any intelligence supporting this transition to smart cities (Deakin & Al Waer, 2011).

What follows proposes that nowhere are these limitations better illustrated than in the notion of

DOI: 10.4018/978-1-4666-8282-5.ch002

smart cities recently advanced by Schaffers et al. (2011), Komninos et al. (2012) and Komninos and Tsarchopoulos (2012). In particular, the idea advanced that smart cities are an index of the future internet and digital technologies which they draw upon to service such developments. What the chapter shall argue runs contrary to this. For it shall propose: smart cities are not an index of the future internet, but instead developments whose full significance can only be understood by challenging the scientific and technical basis of the *"mode 2"* accounts such statements currently stand on. That is to say, by challenging the basis such future internet statements stand on and replacing them with *triple helix accounts* of smart city developments able to account for their evolution (Leydesdorff & Deakin, 2011; Deakin & Leydesdorff, 2013).

Against this backdrop, the second part of this chapter examines the shift from the so-called "mode-2" to triple helix accounts of the relationship between smart city developments and the internet. Drawing upon the critical insights this offers, the third part of the chapter examines the ongoing reconstruction of Montreal and Edinburgh as smart cities and reflects on the critical role the internet plays in their development. The fourth part of the chapter draws upon all of these insights and offers an alternative account of the evolving relationship between smart cities and the internet.

Structured in this way, the chapter avoids the current temptation there is to try and define smart cities by reference to either some pre-defined metrics, or the performance related assessment such developments are associated with. Here any such definitions are set aside because they relate to the very mode 2 thinking this chapter aims to challenge, expose the limitations of and replace with a triple helix inspired account of smart city developments. The definition this chapter aligns with is that offered by Caragliu et al. (2011, p. 70) which suggests a city may only claim to be smart:

… when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government.

This definition is particularly valuable for the simple reason its holistic nature nicely balances the different social, cultural and economic components of smart city developments, without pre-judging either the weight or significance of one relative to the other. Perhaps more significantly, the definition also serves to emphasise the role ICT-related developments play in sustaining economic recovery, underpinning social welfare and supporting cultural health and well-being, by highlighting the internet as an enabler of participatory government.

FROM "MODE-2" TO TRIPLE HELIX ACCOUNTS

The proponents of the "mode-2" thesis argue the social system has undergone a radical transition and this has changed the prevailing mode of knowledge production. They propose disciplinary-based understanding shall increasingly become obsolete and be superseded by techno-scientific knowledge generated in "trans-disciplinary" projects. Advocates of this thesis also propose that it is the economics of the nation-state which provide a stable system for the development of innovations capable of deploying such techno-scientific knowledge, either by way of industrial *sectors, or* through *region*s (Schumpeter, 1939; Lundvall, 1992; Nelson & Winter, 1982; Nelson, 1993; Carlsson, 2006; Braczyk et al. 1998; Carlsson & Stankiewicz, 1991).

Exponents of the triple helix find such accounts of social change wanting and explain the differences between innovation systems (national, sectoral and regional) in terms of *possible* arrangements. Under this knowledge based regime, each system remains in "endless transition" (Etzkowitz & Leydesdorff, 1998). This does not mean "anything goes", but that "emerging systems" should not be reified as yet another "variation on the theme" i.e. as either the sectoral, or regional components of national innovation systems, because the interacting *uncertainties* which the reflexive instability any such meta-stabilization generates, itself does much to determine the global dynamics of the trajectory in question.

Unfortunately, this is what recent accounts of smart cities as "an index of the future internet" end up doing. For while such accounts state any investigation into what is smart should begin with cities, they ignore the dynamics of this trajectory and instead go on to study the "instrumentalization" of the information and communication technologies (ICTs) in question. The problem with such accounts of smart cities is that in setting the trajectory of cities aside and concentrating instead on the ambient intelligence of their ubiquitous computing, everything which is smart about cities is accounted for in terms of the future internet and nothing else. In particular, in terms of the potential the future internet has to make cities smart by exploiting every opportunity the emerging "internet of things" offers them to cultivate a competitive advantage over their rivals and secure this as part of an environmentally sustainable economic growth (Schaffers et al., 2011, pp. 433-437).

The fundamental error such mode 2 inspired accounts of the relationship between smart cities and the internet make, however, is to assume that ideas emerging about the form of content-driven ICT platforms can spin a web strong enough for their 4G cables and wireless sensors to transcend the market. That is to say, spin a web strong enough to transcend the market and set the stage for a set of civic values, which are socially-inclusive in terms of the cohesive qualities any such competitive advantage and environmentally sustainable economic growth offers. The source of the error this particular sector-based and regional "variation on the theme" of national innovation makes rests with the *purely* technical, as opposed to the institutional concepts of civil society the competitive advantage of their environmentally sustainable economic growth labour under.

Unlike mode 2 accounts, the triple helix account of such developments does not rest on an understanding of national innovation systems, be they either sector-based, or regionally-grounded variants on this theme, but instead knowledge of civil society's institutional structures as the embedded intelligence of smart cities (Deakin, 2011, 2013b). As a result, it:

- Studies university-industry-government relations and offers a neo-evolutionary model of knowledge production;
- Proposes the three evolutionary functions cultivating the selection environments of a knowledge based economy are: (i) organized knowledge production, (ii) wealth creation and (iii) reflexive control;
- Suggests that as reflexivity is always involved in knowledge production, the purpose which these three evolutionary functions serve are not given, but *socially constructed* as the science and technology of evolving communication systems operating within given cultural settings. Within cultural settings whose cohesive qualities define the competitiveness of the environments they in turn sustain the growth of in economic terms.

In the triple helix selection dynamics are endogenous because actors in the three institutional domains relate to one another reflexively. As a result, integration and differentiation among the underlying subsystems are concomitant and the functionally differentiated system which evolves is able to process the complexity that surfaces, while the exchange relating to their embedded intelligence makes it possible for new structures to develop. In this dynamic, structures are (re) produced in a system where intellectual capital is associated with universities, wealth creation is linked with industry and regulative control is connected with government. Likewise, within this dynamic, the networking of these relations leads to "degrees of integration" that are not biologically inherited from an ecosystem, but which are socially constructed, both *by way of* cultural attributes and *through* the innovations they (universities, industry and government alike) institute. That is by way of cultural attributes and through the innovations which universities, industry and government institute, systematically enter into, draw upon and generate as products of their "selection environments" (Leydesdorff & Fritsch, 2006; Leydesdorff & Sun, 2009; Etzkowitz, 2008).

Although recognized as important by the likes of Amin and Cohendet (2004), Amin and Roberts (2008) and Nooteboom (2008), the highly distributed nature of these cultural attributes has tended to:

- Overlook the potential this dynamic has to explain what lies behind the surge of academic interest currently being focussed on communities as the "practical" manifestation of intellectual capital and wealth created by industry;
- Ignore how the information systems and communication technologies underlying the notion of "creative cities" and supporting the knowledge base of "intelligent cities" are now intensifying the territorial development of such scientific and technological capacities. What-is-more, intensifying the territorial development of such scientific and technological capacities and representing them as the "embedded intelligence of smart cities".

As Deakin's (2011, 2012a, 2013a) accounts of this transition highlights: what marks smart city contenders out from their counterparts is how they respond to the reflexive instability of this globalisation. In particular, how they react to this globalisation by leveraging the meta-stabilizing tendencies ICTs offer cities to "outsmart their rivals" by transcending the instabilities otherwise associated with the dismantling of national systems and construction of either sector, or regional-based innovation variants on this theme. Instabilities that are otherwise associated with such variations on the theme, but which the embedded intelligence of smart cities transcends. Which the embedded intelligence of smart cities is able to transcend the instabilities of as part of a meta-stabilization that cannot be defined by way of top-level "trans-disciplinary" issues surrounding the future internet. That cannot be defined by way of top-level "trans-disciplinary" issues surrounding the future internet, but only through a considerable amount of cultural reconstruction as to what the embedded intelligence of smart cities means for wealth creation when it gets bottomed out as the "competitive advantage of an "environmentally sustainable economic growth".

THE ONGOING CULTURAL RECONSTRUCTION

The following suggests the decisive level within this transition to smart cities rests not at the national, vis-a-vis either sector-based, or regionally-grounded, but global scale of this development, because it is only under globalization that cities which are not the capitals of nation-states can obtain "world class" status. That is, be(come) the trans-national regions of sectors known to be smart in creating wealth from the innovation processes which the embedded intelligence of these cities in turn cultivate on this scale.

Montreal, for example, has been particularly successful in reinventing itself as a smart city and "creative" sector within the region. (Florida, 2004; Stolarick & Florida, 2006). That is to say, become a city that is smart in not only exploiting the intellectual capital of the creative "sector", but wealth creating opportunities which such a regional innovation system offers. This aside, it should be noted the only thing which is offered to explain how such a cultural reconstruction of Montreal as a world-class city is smart in generating competitive advantage in an environment that sustains economic growth, is a list of locally-specific "prerequisites", such as: university involvement, coupled with a strong scientific and technical development within the creative sector.

In contrast to this, Edinburgh's world-class status is secured by not expounding the corporate, but civic virtue of smart cities. Not on the grounds of either university involvement, or a strong scientific and technical development culture, but based on the ICTs needed for the creative industries to be smart in meeting the evolving e-government requirement (Malina & McIntosh, 2004). Here the City has sought to get beyond policy statements made about the underlying need for university involvement in the scientific and technical development of the creative industries by studying how the application of internet-related developments support their cultural reconstruction (Malina & Ball, 2005).

As with Montreal, the actions taken by Edinburgh serve to highlight the significance of community in bottoming out the embedded intelligence of this cultural reconstruction. In Edinburgh this sense of community has developed into the "IntelCities Community of Practice". However, the intelligence this platform embeds in the city is mainly technical offering the software developments needed to meet the community's e-learning needs, knowledge transfer requirements and capacity building commitments. This currently takes the form of an "eTopia" demonstrator, showing in session-managed logic, how the "eCity platform" accesses the extensive pool of electronically-enhanced services located in the back-office and uses the intelligence embedded in the middleware to be smart in delivering "post-transactional" courses on the consultative needs and deliberative requirements of such developments (Deakin & Allwinkle, 2007).

While Montreal and Edinburgh both serve to highlight how little we know about the relationship between smart cities and the internet, these shortcomings can be explained by reference to their take on the role of science and technology in innovation systems. This is because with mode 2 accounts of this kind, the science and technology of knowledge production is exogenous to the innovation system and as such "manner from heaven". Manner from heaven, that by definition is beyond the reach of national, sector-based or regionally-grounded innovation systems. Beyond the reach of such innovation systems and those which not only smart cities have grown up with, but ideas surrounding the future internet also relate to.

From the vantage point of the triple helix, however, the science and technology of knowledge production in smart cities *can be known.* In particular, both *by way of* the pre-dominantly social situations the science and technology of smart cities institute and *through* the communities the internet not only cultivates, but in practice *systematically opens up, draws upon and constructs* as the selection environment of a *trans-national process.* More specifically, as the selection environment of a trans-national process that *cuts across* the knowledge economy upon which the sustainable growth of such a *regional system* of knowledge production is based.

AN ALTERNATIVE

The following offers just such an alternative account of the emerging relationship between smart cities and the internet and is drawn from the capacity-building outcomes of a North Sea INTERREG 4B project (2008-2011) known as SmartCities. In particular, the capacity-building outcomes of an inter-regional academic network

(SCRAN) whose embedded intelligence underpins this cultural reconstruction and supports the said community's scientific and technical deployment of the internet. In particular, the scientific and technical deployment of the internet as the *means* for the competitive advantage of any environmentally sustainable economic growth to systematically reinvent cities as the smart providers of electronically-enhanced services (Deakin, 2012b; Deakin & Cruickshank, 2013).

After reflecting on the communication needs and technical requirements of such an innovation, this account of smart cities shall go on to configure SCRAN's triple helix and set out the step-wise logic of the organisation's knowledge base. Here attention centres on the University-Industry-Government relations underlying the Web 2.0 service-orientated nature of the enterprise architecture and business models that support this knowledge infrastructure and opportunities which internet-driven developments offer cities to be smart.

The Academic Network

Figure 1 draws attention to the academic network underpinning the SmartCities venture. In this respect, it identifies the network of academic institutions and the specific role they in turn take in supporting SCRAN. For Edinburgh Napier University the main object of attention is the methodology of this venture and for Mechelen

Figure 1. Partners in the SmartCities project

Partners in the SmartCities project

UK
- Edinburgh Napier University
- *City of Edinburgh Council*
- Porism/ESD
- *Norfolk Council*

Belgium
- Mechelin/MEMORI
- *Kortrijk*
- *Leiedal*

Netherlands
- *Gemeente Groningen*
- Groningen University

Germany
- FHS Oldenburg
- *Bremerhaven*
- *Osterholz-Scharmbeck*

Norway
- Agder University
- *Kristiansand-Lillesand*

Sweden
- Karlstad University
- *Karlstad*

University, the object of the exercise is to help the communities of Kortrijk (business and citizens) customise the development of their electronically-enhanced service provision. In this respect, each academic institution (university) within SCRAN is expected to work alongside industry and government, contributing specific expertise towards the development of their electronically-enhanced services.

This representation of the triple helix offers an insight into the science and technology underpinning the growth of smart cities *and* regional innovation systems they in turn support. This is because unlike Etzkowitz and Leydesdorff's (2000, 2002) representation, SCRAN's translation of the triple helix does not rest at the level of institutions, but rather with the cultural construction of the communities whose policies, leadership qualities and corporate strategies make up the *a-priori* knowledge base of the model. That knowledge base which underpins the learning this in turn supports and intellectual capital such a process of wealth creation stands on.

Based on this understanding of knowledge production, the environmental means needed for University and Industry to meet Government's e-service agenda for the growth of smart cities have been assembled as part of a regional innovation system.

SCRAN's Take on the Triple Helix

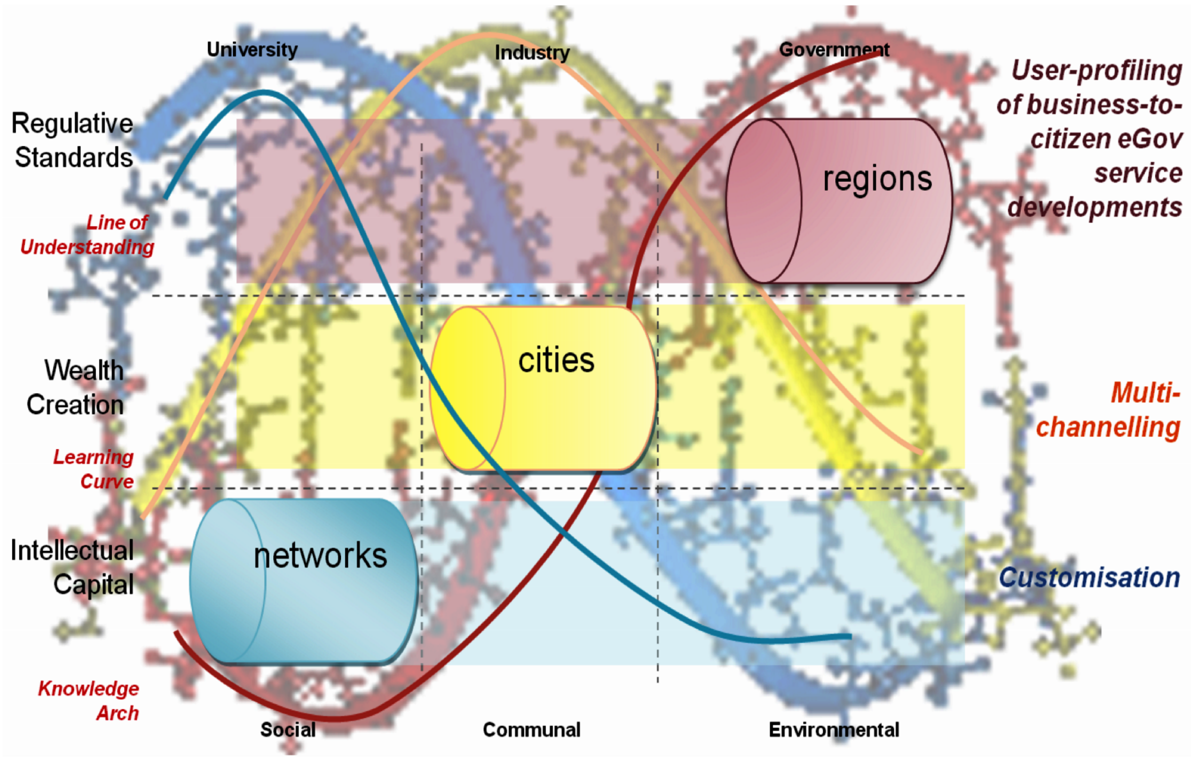
Studies of the triple helix that are socially-grounded and built on the technical infrastructures of university, industry and government collaborations are particularly difficult to find and as a consequence, little is currently known about the way in which the embedded intelligence of smart cities support the development of regional innovation systems. The tendency to focus on the university and industry of regional innovation systems and ignore the technical infrastructures of government, has in turn led some to question the usefulness of the triple helix as a well-grounded and secure model of knowledge production. In this respect, Jensen & Bjorn (2004), Jauhiainen & Suorsa (2008) and Smith (2007), have all recently begun to raise such concerns about the value of the triple helix for these reasons and started to question the usefulness of the model. To overcome these concerns, SCRAN's take on the triple helix has sought to develop practical guidelines on how to take account of not only the social basis, or technical infrastructures of the model, but *all* three strands of the helix, i.e. university, industry *and* government in the process of cultural reconstruction this articulates for the growth of smart cities.

In methodological terms, the challenge this poses means SCRAN has to account for how the triple helix of SmartCities institutionalizes knowledge production.

Figure 2 sets out SCRAN's attempt to overcome the methodological challenges and associated risks such knowledge production raises. In this respect, it offers an initial representation of the triple helix this network advances to begin meeting them. As can be seen, here the three institutional dimensions of SCRAN are: the intellectual capital, wealth creation and regulation of service developments.

- Set out as the actor-network matrix of such institutional relations, it is universities, industry and government which make up the columns of the matrix and their respective contributions to the generation of intellectual capital, wealth creation and the regulative standards of those developments that make up the knowledge production illustrated on the left hand side of the representation. This formal representation of SCRAN's triple helix is then given content by means of the analytical spaces the matrix opens up for the SmartCities venture and opportunity collaborations of this kind offer as three-way partnerships able to cut across a regional innovation system.
- This networking of SmartCities as a regional innovation system in turn relates

Figure 2. SCRAN's triple helix



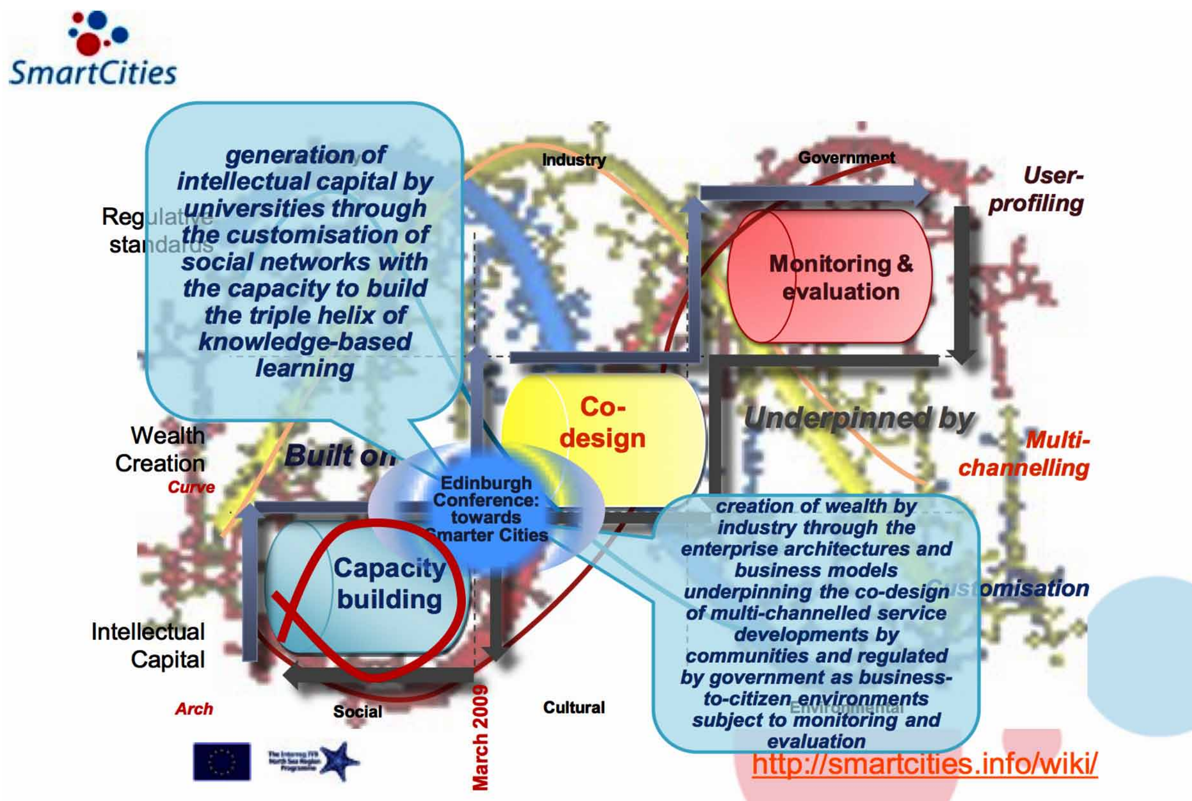
the universities engaged in the generation of intellectual capital, industries involved in the creation of wealth and standards of regulation government in turn sets for this, back to those actors associating with one another as a community of learners. What the wealth created from this process of knowledge production in turn contributes to such a learning organisation is represented in the right hand column of the matrix. This is shown in terms of the advantage that such a venture constructs as a platform of wealth creation which regulates the development of electronically-enhanced services.

- All of this is then captured in the right-hand column and in terms of what the knowledge produced by the SmartCities venture contributes to the development of electronically-enhanced services as part of this regional innovation system. That is to say, by way of and through the associated capital of a community set up to regulate the customisation of electronically-enhanced service developments, the wealth created from their co-design and knowledge this produces about the user-profiles regulating their direct participation in this governance-led democratisation of the regional innovation system.

The Triple Helix of SmartCities

Revealing how the triple helix of the SmartCities venture can be mutually advantageous is however, not so simple. Figure 3 illustrates this as a second-order configuration of the triple helix. This shows universities as being responsible for building the capacity of the enterprise architecture and business models, acting as a platform for industry to

Figure 3. The triple-helix of SmartCities



customise the development of electronically enhanced services. Those electronic enhancements that in turn offer multi-channelled access (cable and wireless, PC and mobile) to such services and target specific user-profiles (classified by demographic groups and community membership). Represented in this way, it is possible to be specific about the duties and responsibilities of SCRAN's triple helix.

For as this figure shows, while the work packaged together under the titles of: customisation, multi-channel access and user-profiling, provide the backdrop to SCRAN, it is not proposed the SmartCities venture should cover all of them. Rather it suggests SCRAN should use the triple helix as a means to cut across them, concentrating instead on the efforts of the network's associated communities to learn about (get information on and gain knowledge of) how cities can be smart. In particular, on how cities can be smart in building the capacity needed for the intellectual capital of this knowledge-base to be quintessentially civic in supporting the co-design, monitoring and evaluation requirements of such applications.

This is an important point and begins to throw some light on what is smart about the capacity building exercises cities are entering into. For what it shows is that "being smart" *does not rest so much* with the technologies which support cities, *as with* the generation of intellectual capital, creation of wealth and regulative standards underlying their application. In particular, the intellectual capital whose experiential learning provides communities with the capacity to build such a platform and then go on and exploit the "ambient intelligence" *this* innovation in the process of wealth creation cultivates as environments supporting the co-design, monitoring and evaluation of electronically-enhanced services.

The significance of this rests with the realization that with the triple helix of smart cities, it is the intellectual capital making up the experiential learning of this knowledge base, which provides a *true* index of smart cities. For only in sourcing the “ambient intelligence” of this intellectual capital on *standards* that are pre-dominantly social, as opposed to technical and civic rather than instrumental, can the cohesive qualities of this knowledge base be openly sourced (as opposed to privately appropriated via rivalry and competition). Openly sourced and appropriated by communities as a *measure* of the wealth creation which their environments *regulate, both by way of and through, the standards* that are set collectively i.e. as part of a *democratic process for governing* the co-design, monitoring and evaluation of electronically-enhanced service developments.

Accounted for in this way and in the interests of serving the social dynamic of this innovation process, it does now become possible to highlight the knowledge base and learning curve of SCRAN’s triple helix. What this also brings to light is the step-wise logic of the network’s particular take on the institutionalisation of the model: the fact the intellectual capital that it generates builds off a given knowledge base, vis-à-vis an embedded system and is creative in using the wealth of industry, which underpins this learning organisation. That learning organisation which in turn provides the platform for what might best be termed: the critical “building-blocks” of smart cities and service developments *regulating their governance-led* democratisation of regional innovation systems.

Figure 4 sets out how the electronically-enhanced services developed under the SmartCities venture serve the social dynamic of this cultural reconstruction. It also outlines the pedagogy needed for the wealth created from such developments to be regulated in such a way the direct participation of communities in this process is not only inclusive, but equitable in meeting the governance requirements of the emerging regional innovation system.

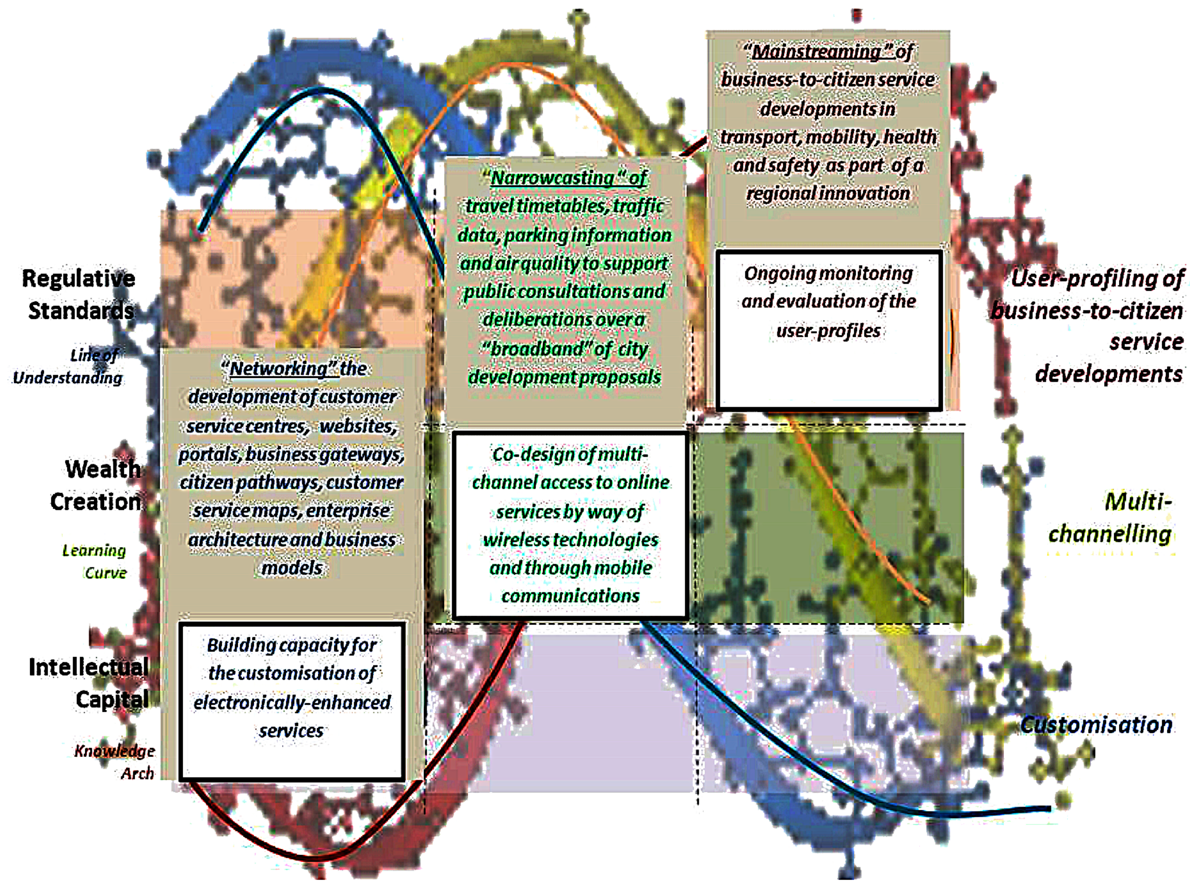
Reading from bottom left to top right, Figure 4 serves to affirm the third mission basis of the research, science and technology underpinning the SmartCities venture. This is set out in terms of the university engagement and intellectual capital society draws upon to build capacity for the customisation of electronically-enhanced services, the platform this offers industry to create wealth from their co-design by communities and provision of multi-channel access to these developments, both by way of wireless technologies and through mobile communications. It also reaffirms the standards of regulation set for this development by way of and through the ongoing monitoring and evaluation of their user-profiles.

This in turn also serves to confirm the content of this customisation, multi-channel access, monitoring and evaluation of the service developments is founded on the:

- Networking of customer service centres, websites, portals, business gateways, citizen pathways, customer service maps, enterprise architecture and business models;
- Narrowcasting of travel timetables, traffic data, parking information and air quality to support public consultations and deliberations over a broadband of city development proposals;
- Mainstreaming of business-to-citizen service developments in transport, mobility, health and safety as part of a regional innovation.

This also helps to clarify some of the methodological issues surrounding SmartCities. For it illustrates the bottom-line of this triple helix is not grounded in the science and technology of either fundamental, or applied research, but embedded in the networks of third-mission capacity-building exercises. Third mission capacity-building exer-

Figure 4. The electronically-enhanced service developments of SmartCities



cises that are social and culturally constructive in assembling the enterprise architectures and business models which industry need to co-design electronically-enhanced services with communities. In particular, co-design them by way of wireless technologies and through mobile communication systems. Wireless technologies and mobile communications themselves capable of narrowcasting the travel timetables, traffic data, parking information and air quality data needed to inform public consultations and deliberations about a broadband of city development proposals. About a broadband of city development proposals in turn mainstreamed across this platform as business-to-citizen applications in transport, mobility, health and safety services.

This also serves to reiterate the knowledge base of SCRAN as a learning organisation. For while firmly grounded in the social knowledge base of this cultural reconstruction, it is how industry and communities draw upon this embedded intelligence as a platform for wealth creation to govern the co-design of electronically-enhanced services which has to be learnt about. If only so the narrowcasting of travel timetables, traffic data, parking information and air quality, which *the innovation system underpinning this process of wealth creation produces a knowledge* of, can support the public consultations and deliberations that such a broadband of smart city development proposals calls for. Those public consultations and deliberations such a broadband of smart city development calls for and they in turn mainstream as business-to-citizen applications in transport, mobility, health and safety services.

As critical components of smart cities, the social media and attending digital technologies underlying these developments need linking together and require to be connected with one another as part of a supporting network. Consequently, it is the networking of the social capital underlying the embedded intelligence of this knowledge production and surfacing as the wealth of electronically-enhanced services created from this governance-led democratisation of their regional innovation system, the SmartCities venture is now turning particular attention to. For it goes without saying that any claim which is made about a network's innovative status, has to extend beyond the name it is known. That is beyond the notion of an "inter-regional academic network" which has been deployed so far. Beyond this and into both the culturally specific attributes and environments communities assemble for regional innovation systems to regulate as *"trans-national"* standards. As the trans-national standards of regional innovation systems communities not only directly participate in setting, but smart cities also uphold as the means to govern the democratisation of electronically-enhanced service developments within the public realm.

CONCLUSION

Reflecting on the emergence of smart cities, this chapter has drawn upon the triple helix as the means to advance a critique of recent mode 2 accounts advanced to explain their development. This has subjected the idea of smart cities as an index of the "future internet" to scrutiny and found the typology advanced to explain their trajectory wanting. It instead has sought to explain the emergence of smart cities in terms of the social media and digital technologies of information-based communication systems currently exploited to generate the notion of "creative cities," as the knowledge base of intelligent cities and platform for their augmentation into smart cities. Cities that are smart in deploying ICTs because the embedded intelligence of their cultural attributes are not only creative, but also intelligent. Not only creative, but also intelligent in generating the intellectual capital that is needed for wealth creation to cultivate the selection environments required in order for smart cities to govern this process of knowledge production.

The social dynamic of this augmentation has also been shown to be significant in the sense which this begins to throw some light on what is smart about the capacity building exercises that cities are entering into. That is to say, begins to reveal what is smart does not rest so much on the technologies which support cities, as with the generation of intellectual capital. With the generation of intellectual capital whose experiential learning provides communities with the capacity to build such a platform and then go on to exploit the "ambient intelligence" of the wealth their multi-channelled access to given user-profiles creates as "smart environments" supporting the co-design, monitoring and evaluation of electronically-enhanced services. Smart environments that not only support the co-design, monitoring and evaluation of electronically-enhanced services, but which underpin the highly consultative and deliberative processes securing the direct participation of communities in this post-transactional democratisation of online provision

From this vantage point, the science and technology of smart cities can be known. In particular can be known by way of the pre-dominantly social situations the science and technology of smart cities institute and through the communities the internet not only cultivates, but in practice systematically enters into, draws upon and constructs as the selection environments of a trans-national process. Specifically, as a trans-national process that cuts across the creative industries upon which the knowledge economy is based and sustainable growth of such a regional innovation system rests.

Using this neo-evolutionary perspective on the triple helix of smart cities, the role social media play in the digital technologies of this cultural reconstruction also comes to the fore. For the triple helix of smart cities indicates the growth of such territories is not a spontaneous product of either national, sector-based, or regionally-grounded systems, but the outcome of the social situations, policies, academic leadership qualities and corporate strategies, which all need to be carefully constructed, pieced together, and articulated. This goes some way to overcome the gaps in previous representations of the model by using the networking possibilities social capital offers to be reflexive and stabilise cities. That is stabilise cities whose futures are smart in the sense which their embedded intelligence generates capital *and* creates wealth, which in this instance is secured, not from the internet, but the governance of electronically-enhanced services as business-to-citizen applications.

It is the embedded intelligence of this government-led transformation that defines smart cities and which gives the term its distinctive qualities. For unlike rival notions of both "creative" and "intelligent" cities, the social dynamic of the cultural reconstruction that smart cities are wrapped up in does not merely develop the intellectual capital i.e. networked knowledge infrastructure underpinning any such transition, but the "next order logic" which in turn supports the enterprise architecture and business models of their regional innovation systems.

As such, the distinctive feature of this next order rests not with either the "creativity", or "intelligence" of the knowledge infrastructure all of these electronic enhancements are embedded in, but with the "co-design" of the services they rest on and are built with. This is because the ubiquitous computing underlying this "order of things" extends beyond universities and into industry by way of communities. By way of communities that surface through industry's deployment of wireless technologies in regional innovation systems, which in turn make it possible for the intelligence all of this wealth creation stands on to become ambient.

This serves to highlight what is so pivotal about the social media and digital technology of such developments. For they serve to:

- Underpin the social status of smart cities in the generation of intellectual capital, creation of wealth and regulative standards that communities can openly source and which provide them with a measure of good governance;
- Support the actions taken by communities to uphold such values and openly source the intellectual capital this in turn generates as the wealth of policies, leadership qualities and corporate strategies of the ICTs they stand on;
- Cultivate a bottom-up, capacity-building logic for smart cities and a "third mission" pedagogy, capable of constructing the knowledge arch and learning curve of their communities;
- Assemble the enterprise architecture underpinning this venture and business model supporting their development;
- Build the relationship between smart cities and the internet from the bottom-up and establish them as a top level issue for policy makers, academic leaders and corporate strategists alike;
- Allow these communities in turn to recognise their participation in the cultural reconstruction underlying this transition to smart cities is not limited to either the ambience of the intellectual capital, or wealth creation such environments support, but cuts deeper than this. That is into the customisation and co-design of electronically-enhanced services on which the ubiquity of their multi-channelled applications in turn rest;

- Make it possible for communities to also participate in the monitoring and evaluation of these electronic enhancements via the user-profiles that are set up independently to regulate the standards of the services which are under development;
- Provide the means for smart cities to demonstrate a commitment to the public realm by openly sourcing and cultivating the direct participation of communities via the highly consultative and deliberative i.e. e-democratic stages of their on-line service developments;
- Ensure the cultural reconstruction of smart cities is based on a regional innovation system whose reflexive instability recognizes that such meta-stabilizing tendencies should not only tackle the digital divide, but be socially-inclusive and equitable in going about this. That is to say, be socially-inclusive and equitable, not only in terms of the cohesive qualities such developments contribute to the competitiveness of an environmentally sustainable economic growth, but climate adaptation strategy which they also call hard and loud for.

Not only does this representation of their social dynamic overcome the limitations of mode 2 accounts, but it also offers a neo-evolutionary perspective of a triple helix, whose reflexive stability and meta-stabilization sets the growth of smart cities within the context of regional innovation systems.

ACKNOWLEDGMENT

The author would like to acknowledge Loet Leydesdorff, Amsterdam School of Communication Research (ASCoR), University of Amsterdam, for his intellectual contribution to the first part of this chapter.

REFERENCES

Amin, A., & Cohendet, P. (2004). *Architectures of Knowledge*. Oxon: Oxford University Press. doi:10.1093/acprof:oso/9780199253326.001.0001

Amin, A., & Roberts, J. (2008). Knowing in action: Beyond communities of practice. *Research Policy*, *37*(2), 353–369. doi:10.1016/j.respol.2007.11.003

Braczyk, H., Cooke, P., & Heidenreich, M. (Eds.). (1998). *Regional Innovation Systems*. London: University College Press.

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *16*(2), 65–82. doi:10.1080/10630732.2011.601117

Carlsson, B. (2006). Internationalization of innovation systems: A survey of the literature. *Research Policy*, *35*(1), 56–57. doi:10.1016/j.respol.2005.08.003

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function, and composition of technological systems. *Journal of Evolutionary Economics*, *1*(2), 93–118. doi:10.1007/BF01224915

Deakin, M. (2011). The embedded intelligence of smart cities. *International Journal of Intelligent Buildings*, *3*(2), 189–197. doi:10.1080/17508975.2011.579340

Deakin, M. (2012a). Intelligent cities as smart providers: CoPs as organizations for developing integrated models of eGovernment Services. *Innovation: The Journal of Social Research*, *23*(2), 115–135.

Deakin, M. (2012b). SCRAN: Assembling a Community of Practice for Standardizing the Transformation of eGovernment Services. In S. Aikins (Ed.), *Managing E-Government Projects: Concepts, Issues and Best Practices*. Hershey, PA: ICI Publisher.

Deakin, M. (2013a). Introduction (to smart cities). In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M. (2013b). The embedded intelligence of smart cities. In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M., & Al Waer, H. (2011). From intelligent to smart cities. *Intelligent Building international, 2(3)*, 140-152.

Deakin, M., & Allwinkle, S. (2007). Urban regeneration and sustainable communities: The role networks, innovation and creativity in building successful partnerships. *Journal of Urban Technology*, *14*(1), 77–91. doi:10.1080/10630730701260118

Deakin, M., & Cruickshank, P. (2013). SCRAN: the network. In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M., & Leydesdorff, L. (2013). The triple helix of smart cities: a neo-evolutionary perspective. In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Etzkowitz, H. (2008). *The Triple Helix: University-Industry-Government Innovation in Action*. London: Routledge. doi:10.4324/9780203929605

Etzkowitz, H., & Leydesdorff, L. (1998). The Endless Transition: A "Triple Helix" of University-Industry-Government Relations, Introduction to a Theme Issue. *Minerva*, *36*(3), 203–208. doi:10.1023/A:1004348123030

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy*, *29*(2), 109–123. doi:10.1016/S0048-7333(99)00055-4

Etzkowitz, H., & Leydesdorff, L. (2002). *Universities and the Global Knowledge Economy NIP: A Triple Helix of University-Industry Relations*. Continuum International Publishing Group Ltd.

Florida, R. (2004). *The Rise of the Creative Class: A Toolkit for Urban Innovators*. New York: Basic Books.

Hollands, R. (2008). Will the real smart city please stand up? *City*, *12*(3), 302–320. doi:10.1080/13604810802479126

Jauhiainen, J., & Suorsa, K. (2008). Triple Helix in the periphery: The case of Multipolis in Northern Finland. *Cambridge Journal of Regions*. *Economy and Society*, *1*(2), 285–301.

Jensen, J., & Bjorn, T. (2004). Narrating the Triple Helix concept in "weak" regions: Lessons from Sweden. *International Journal of Technology Management*, *27*(5), 513–530. doi:10.1504/IJTM.2004.004287

Komninos, N. (2008). *Intelligent Cities and Globalisation of Innovation Networks*. London: Taylor & Francis.

Komninos, N., Pallot, M., & Schaffers, H. (2012). Special Issue on Smart Cities and the Future Internet in Europe. *Journal of Knowledge Economy*, *4*(2), 119–134. doi:10.1007/s13132-012-0083-x

Komninos, N., & Tsarchopoulos, P. (2012). Intelligent Thessaloniki: From agglomeration of apps to smart districts. *Journal of Knowledge Economy*, *4*(2), 149–168. doi:10.1007/s13132-012-0085-8

Landry, C. (2008). *The Creative City*. London: Earthscan.

Leydesdorff, L., & Deakin, M. (2011). The triple helix of smart cities: A neo-evolutionary perspective. *Journal of Urban Technology*, *18*(2), 53–63. doi:10.1080/10630732.2011.601111

Leydesdorff, L., & Fritsch, M. (2006). Measuring the knowledge base of regional innovation systems in Germany in terms of a triple helix dynamics. *Research Policy*, *35*(10), 1538–1553. doi:10.1016/j.respol.2006.09.027

Leydesdorff, L., & Sun, Y. (2009). National and international dimensions of the triple helix in Japan: University-industry-government versus international co-authorship relations. *Journal of the American Society for Information Science and Technology*, *60*(4), 778–788. doi:10.1002/asi.20997

Lundvall, B. (1992). *National Systems of Innovation*. London: Pinter.

Malina, A., & Ball, I. (2005). ICTs and community: Some suggestions for further research in Scotland. *Journal of Community Informatics*, *1*(3), 66–83.

Malina, A., & McIntosh, A. (2004). Bridging the digital divide: The development in Scotland. In A. V. Anttiroiko et al. (Eds.), *eTransformation in Governance*. London: Idea Group Publishing. doi:10.4018/978-1-59140-130-8.ch013

Nelson, R. (1993). *National Innovation Systems: A comparative analysis*. New York: Oxford University Press.

Nelson, R., & Winter, S. (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap Press of Harvard University.

Nooteboom, B. (2008). Cognitive distance between communities of practice and in firms. In A. Amin & J. Roberts (Eds.), *Community, Economic Creativity and Organisation*. Oxon: Oxford University Press. doi:10.1093/acprof:oso/9780199545490.003.0006

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., & Oliveira, A. (2011). Smart Cities and the Future Internet: towards cooperation frameworks for open innovation. In J. Domingue et al. (Eds.), *The Future Internet* (pp. 431–446). Lecture Notes in Computer Science Springer. doi:10.1007/978-3-642-20898-0_31

Schumpeter, J. ([1939], 1964). Business Cycles: A Theoretical, Historical and Statistical Analysis of Capitalist Process. New York: McGraw-Hill.

Smith, H. (2007). Universities, innovation, and territorial development: A review of the evidence. *Environment and Planning C*, *23*(1), 98–114. doi:10.1068/c0561

Stolarick, K., & Florida, R. (2006). Creativity, connectivity and connections: The case of Montreal. *Environment & Planning A*, *38*, 1779–1817.

KEY TERMS AND DEFINITIONS

Capacity Building: Refers to assistance, provided to organisations, which have a need to develop a certain skill or competence, or a general upgrading of performance ability. Most capacity is built by society, sometimes in the public, on other occasions in the non-governmental and independent sectors. They are activities, which strengthen the knowledge, abilities, skills and behaviour of individuals and improve institutional structures and processes, so organization can efficiently meet its mission and goals in a sustainable way.

Co-Design: Here there is an understanding that all human artifacts are designed and with a purpose. In the process of co-design, communities try to include the views and opinions of others when designing products, because it is recognized the quality of the goods and services developed increases if the stakeholder's collective interests are accounted for.

Community of Practice: Groups of people who share a concern or a passion for something they do and learn how to do it better as they regularly interact with one another as knowing subjects.

Community: The term is derived from the word *communité*, which is derived from the Latin *communitas* (*cum*, "with/together" + *munus*, "gift"), a broad term for fellowship or organized society. In biological terms, a community is a group of interacting species sharing an environment. In human communities, intent, belief, resources, preferences, needs, risks, and a number of other conditions may be present and common, affecting the identity of the participants and their degree of cohesiveness. In sociology, the concept of community has led to significant debate, and sociologists are yet to reach agreement on a definition of the term. Traditionally a "community" is defined as a group of interacting people, living in a common location. The word is often used to refer to a group organized around common values and is attributed with social cohesion within a shared geographical location, generally in social units larger than a household. The word can also refer to the national community or global community. Since the advent of the Internet, the concept of community no longer has geographical limitations, as people can now virtually gather in an online community and share common interests as citizens regardless of physical location.

Digital Inclusion: Encompasses activities related to the achievement of an inclusive information society. In this vein, new developments in technology turns the risk of a digital divide into "digital cohesion" and opportunity, bringing the benefit of the internet and related technology into all segments of the population, including people who are disadvantaged due to education, disabilities, gender, ethnicity, or those living in remote regions. Digital inclusion covers mainly the development of appropriate policies, maintenance of a knowledge base, research and technology development and deployment and best practices dissemination.

E-Government Services: Are internet technologies that act as a platform for exchanging information, providing services and transacting with citizens, businesses, and other arms of government. Such e-Government services include: pushing information over the Internet, e.g. regulatory services, general holidays, public hearing schedules, issue briefs, notifications, etc; two-way communications between the agency and the citizen, a business, or another government agency. In this model, users can engage in dialogue with agencies and post problems, comments, or requests to the agency; conducting transactions, e.g. lodging tax returns, applying for services and grants; governance, e.g. online polling, voting, and campaigning. The most important anticipated benefits of e-government include improved efficiency, convenience, and better accessibility of public services.

E-Learning: A general term used to refer to a form of learning in which the instructor and student are separated by space or time where the gap between the two is bridged through the use of online technologies. The term is used interchangeably in a wide variety of contexts and can be used to define a specific mode to attend a course or programmes of study where learners rarely, if ever, attend face-to-face contact, or rely upon such direct support.

Governance: Is the activity of governing. It relates to decisions that define expectations, grant power, or verify performance. In terms of distinguishing the term governance from government - "governance" is what a "government" does. It might be a geo-political government (nation-state), a corporate government (business entity), a socio-political government (tribe, family, etc.), or any number of different kinds of government. But, irrespective of this, governance is the kinetic exercise of managing power and administering policy.

Knowledge Transfer: The practical problem of transferring knowledge from one part of the organization to another (or all other) parts of the organization. It seeks to organize, create, capture or distribute knowledge and ensure its availability for future users. It is more than just a communication problem and more complex because: knowledge resides in organizational members, tools, tasks, and their sub-networks and much of the knowledge organizations have is tacit or hard to articulate in direct communication.

Open Source Software: Computer software for which the human-readable source code is available under a copyright license, or arrangement. This permits users to use, change, and improve the software, and to redistribute it in modified or unmodified form. It is developed in a collaborative manner.

Triple Helix: In this model, three spheres are defined institutionally (university, industry, and government) as interactions, mediated across otherwise defended boundaries, both by way of communication systems and through the technological innovations, they generate. The interfaces among these different functions operate in a distributed mode that produce knowledge of these communication systems and technical innovations. While communication and technical innovation are fundamental to this process of knowledge production, in a scientific based knowledge economy, growth serves to intensify the environmental and cultural complexity of these interactions and act as a means for civil society to capitalize on the intelligence such an institutionalization of wealth creation generates.

Chapter 3
Evaluating the Smart and Sustainable Built Environment in Urban Planning

Patrizia Lombardi
Politecnico di Torino, Italy

Silvia Giordano
Politecnico di Torino, Italy

ABSTRACT

The measurement of urban performance is one of the important ways in which one can assess the complexity of urban change, and judge which projects and solutions are more appropriate in the context of smart and sustainable urban development. This chapter introduces a new system for measuring urban performances. This is the result of two years of joint cooperation between the authors and the Italian iiSBE members group. It is based on previous research findings in the field of evaluation systems for the sustainable built environment. This new approach is useful for evaluating smart and sustainable urban redevelopment planning solutions, as it is based on benchmarking approaches and multi-scalar quantitative performance indicators (KPIs), from individual building level to city level. A number of important implications of the main findings of this study are set out in the concluding section, together with suggestions for future research.

INTRODUCTION

Policy-makers are specifically challenged by the need to achieve sustainable development in cities, promoting a transition that radically decarbonises energy sources without undermining wellbeing and patterns of consumption. This scenario is known as Energy Transition towards a Post-Carbon Society. However, if not properly designed, policies aimed at reducing greenhouse gas emissions may affect the resilience of our energy system and its ability to tolerate disturbance and deliver stable and affordable energy services to consumers (ftp://ftp.cordis.europa.eu/pub/fp7/ssh/docs/towards_post_carbon_society_en.pdf).

Moreover, European urban areas have to respond properly and urgently in order to preserve their attraction for creative talents and firms, and

DOI: 10.4018/978-1-4666-8282-5.ch003

to avoid any reduction in their level of 'liveability'. This leads to a new '*urban imperative'* and raises the whole question of long-term strategies for sustainable development (JPI, 2010).

Cities are dynamic living organisms that are constantly evolving. Rees (1997) describes cities as the engines of economic growth, the centres of social discourse and the living repositories of human cultural achievement, but also as nodes of pure consumption and the entropic black holes of industrial society. When addressing the complex problems of city management and planning, it is not sufficient to be concerned simply with the physical structure of the city; the interplay of intangible economic, social and environmental factors needs to be considered in a holistic way as well. This represents a substantial challenge for those political and technical actors (planners, designers and urban authorities) trying to devise smarter strategies and policies, urban plans and projects that can guide cities along a more sustainable development path.

City planning and urban re/development decision-making is recognized as being an extremely complex process involving a wide range of stakeholders, and requiring an integrated and holistic system approach (Veirier, 2008; Brandon & Lombardi, 2011). Key requirements are robust real-time information and analysis systems which depend on integrated dimensional databases of city indicators. These include both a detailed profiling of societal and user needs, as well as the development of an advanced integrated information technology system in local government.

Because of the complexity of the urban planning problem, development control is often characterised by adversarial decision-making processes that can provide a significant disincentive to inward investment, undermining business confidence and competitiveness. In particular, new processes are needed that can re-engineer urban re/development planning so as to streamline policy implementation and decision-making, which in turn can support more sustainable urban regeneration and the improved growth and competitiveness of cities and their constituent business components.

According to Roberts and Hughes (2006), "Urban regeneration is a widely experienced but little understood phenomenon … [and] there is no single prescribed form of urban regeneration practice … One of the major difficulties [is] … the absence of quality literature that encompasses the whole of the organisation and functioning of the urban regeneration process."

Recent research findings highlight the fact that decisions on city design and planning can only be based on the preferences of citizens. Otherwise they will fail. Therefore, mechanisms need to be found to ensure that citizens understand the issues and options, and can express their preferences; a great deal of social science research is still needed to understand the interaction between city design, social preferences, human behaviour, economic issues and policy incentives.

The Operational Implementation Plan recently developed by the European Innovation Partnership on Smart Cities and Communities (http://ec.europa.eu/eip/smartcities/files/operational-implementation-plan-oip-v2_en.pdf) highlights the need for the joint-creation of platforms and decision tools (simulation, visualization/virtualization, open data/information platforms) in order to increase levels of awareness, increase inhabitants' involvement in the planning and implementation processes, establish social communities, increase energy production within the district (by "prosumers"), and increase the provision of information-intensive energy services.

There are more than 150 city indicator systems in place, covering a series of different criteria including geographical and thematic issues. In addition, a remarkable number of methods have been developed aimed at evaluating sustainability in the built environment (Brandon & Lombardi, 2011). Current methods seem unable to cope with complex, systematic decisions leading to correct policy action regarding urban resilience and social well being. More specifically, a number of rating systems, evaluation protocols and Form-Based Design Codes at neighbourhood level, have emerged in recent years. The best known and most popular such systems are: LEED for Neighbourhood Development (USA), BREEAM Communities (GB), CASBEE for Urban Development, CASBEE for Cities (Japan), HQE Aménagement Urbain (France), DGNB Stadtquartiere (Germany). These systems do not consider the city as a whole, but act at the micro level by analysing an individual urban area. They seem to be the only possible alternative when considering everything that does not operate at individual building level. Nevertheless, the aforementioned systems are not able to account for urban dynamics at different levels (closely related to one another) using one single, holistic, trans-scalar approach. They are unable to shift from cluster level to district level, and from district level to city level. Moreover, current rating systems are conceived as mechanical ex-post evaluation approaches, rather than decision-support systems capable of supporting the entire project cycle management process.

According to Lombardi et al. (2010), new metrics for "Value Creation" should be established based on different approaches. One dimension is the built environment, where the present rating schemes focus on the environmental impact of building use, that is, on a building's energy use. Another dimension is the corporate aspect, where triple bottom line reporting also emphasizes environmental and social issues, although the discursive civic square environment risks being subordinated to the economic sustainability of the productive, growth-oriented business environment. The third dimension is the city itself with its social networks (Batty, 2013), evaluated by the indicators of employment and crime for example. The fourth dimension aims to measure the quality of life of individual citizens, a concept that is not easy to define. At the present, all four approaches are employed separately, and there is no interoperability between these systems.

Innovative methodologies and more appropriate tools are required to support decision makers and stakeholders in fostering smart urban development and regeneration processes. Although environmental sustainability is not a new issue for urban planning, the evaluation of complex urban (spatial, environmental, social, economic and governance) dynamics through quantitative and objective metrics, represents a new trend.

This chapter critically analyses the principal shortcomings of current indicator systems and tools (see Section 2), and briefly illustrates a new method of measuring urban performances (see Section 3). This new system is based on multi-scalar quantitative performance indicators (KPIs), from individual building to city level. The chapter also presents a number of tests and audits of the system as employed in the case of the Italian city of Turin. The conclusion points to a number of important implications of the main findings of the study, together with possible future directions for such.

A CRITICAL OVERVIEW OF CURRENT INDICATORS, SETS, AND TOOLS

With the term "smart city", the European Commission often refers to systemic approaches and organisational innovation, encompassing energy efficiency, low carbon technologies and the smart management of off-peak demand. The most untapped innovation potential and the best environmental and societal benefits to be gained are coupled with the integration of the Energy, Transport, and Information and Communication Technologies (ICT) sectors. However the main question remains: "how can a city develop a measure of these actions, and how can any improvement in performances along these line be mainstreamed across the EU?".

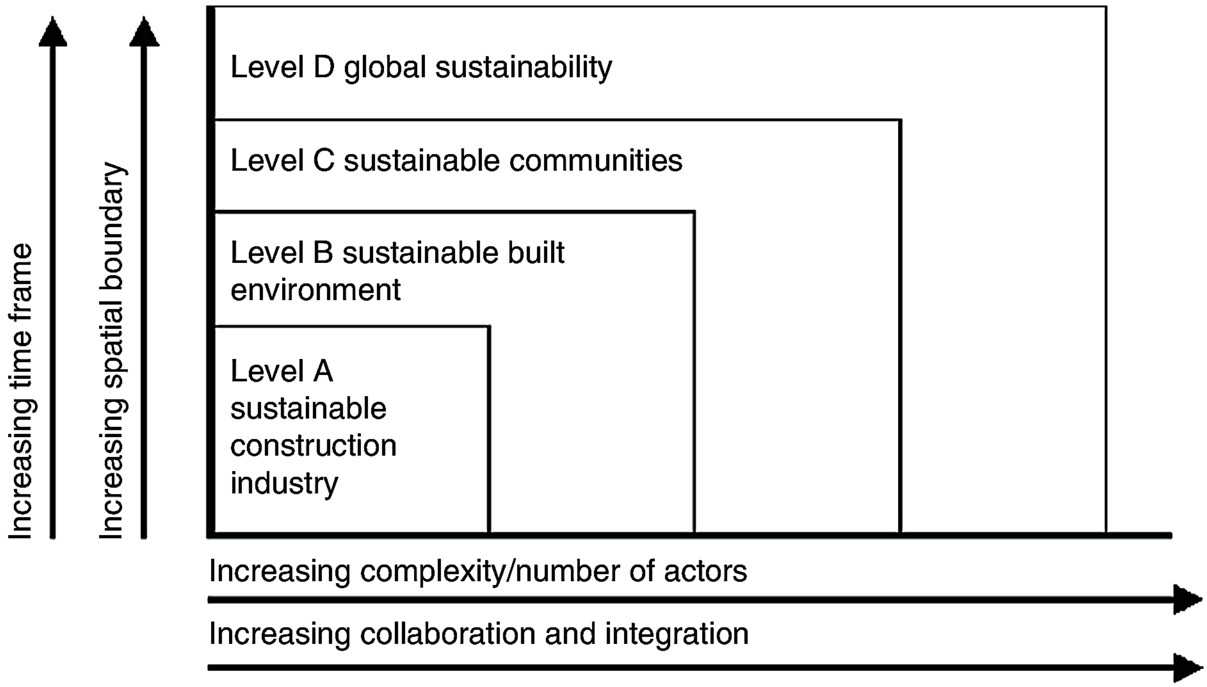
This question arises because there is currently no common framework that cities can use to analyse such performances, or transfer knowledge of how to be smart in mainstreaming such improvements across the regions. Initial attempts to develop such frameworks have been recorded, for example via Smart City Ranking indices, Future Internet and Triple Helix inspired models of smart city performances, but as yet they stand as prototypes around which consensus needs to be built as a basis for cooperation between key stakeholders within the smart city community, and for the further consolidation of these frameworks as a common set of measures (Deakin, 2013).

Currently, there are hundreds of official or recognised full sustainable indicator sets in use, and many more that have been informally developed, or have been created as a subset of the larger agenda (Alwaer & Clement-Croome, 2010; AlWaer et al., 2014). More recently, key European-level performance indicators (KPIs) have been developed with the aim of forming a common base for developing sustainability assessment, and addressing the main issues of sustainable building, which include (CESBA, 2014; Brandt et al., n.d.): Non-renewable primary energy; Primary renewable energy use; Co_2 emissions; Indoor air quality; Thermal comfort; Life cycle costs; Reused/recycled materials; Water consumption; Solid waste; Users' involvement; Monitoring/optimization of operation.

As we all know, KPIs are indexes of performance employed to evaluate the success of a particular activity or its achievement of/progress towards strategic goals. Accordingly, choosing the right KPIs requires a good understanding of what is important to the achievement of sustainable development in an urban environment. One common way of choosing KPIs is to apply a management framework, such as the balanced scorecard. Unfortunately, at the urban level these scorecards are not easily developed. This is because of the complexity of the urban system and the different needs or viewpoints of the involved stakeholders, as represented in Figure 1.

This figure attempts to show the relationship between different parts of the built environment,

Figure 1. Levels of response to sustainable development
(Source: Brandon & Lombardi, 2011)



including the communities that exist within it and the global environmental agenda. It shows the broad areas that need to be addressed for sustainability when viewed from the built environment perspective, placing the focus on particular groups of decision-makers. Broadly speaking, level 'A' would be addressed by the building contractors, consultants and clients of individual structures, level 'B' would be primarily planners and local government, and level 'C' would be the province of central government (Brandon & Lombardi, 2011). Ideally, we would want a common structure that allowed information to flow freely from one level to another, together with a common language, to allow full communication both across disciplines and between different levels. Delivering SD metrics effectively will require moving beyond the professions' comfort zones.

The modern Sustainable Development Indicator (SDI) process started at the Rio Earth Summit in 1992. Since then, many data sets have been developed, including several attempts at creating aggregated or composite indicators in order to account for various aspects of sustainable development. Such indicators include the European Commission's 10 Common Indicators, the UN Division for Sustainable Development's indicators of sustainable development, and also health-related indicators such as the World Health Organization's Healthy Cities Project (UN, 2004). Most of them specifically focus on the environmental aspects of sustainable development and resource management, and they are mainly used for raising public awareness, and receive attention in the media (UN, 2007). The most valuable indicators are the ones that have been sustainable and allow for trend analysis. There are very few city indicators, if any, that are regularly collected and are relevant across cities worldwide. The closest program that exists is UN-HABITAT's Global Urban Indicators Database. This comprises 20 key (quantitative) indicators, 9 (qualitative) checklists, and 13 extensive (performance) indicators of diverse origin, including the City Development Index (CDI) ranking cities according to their level of development (UN, 2006). At the urban level, data generation and collection are limited by the lack of comparable data. To overcome this obstacle, the OECD has developed a Metropolitan database that defines urban areas by functional, rather than administrative, boundaries, allowing for comparisons of cities across the OECD. Currently, data are being collected for 17 indicators in over 200 urban areas across the OECD (OECD, 2011; OECD, 2012).

There has been an additional focus on the development of sets of indicators, standards, codes and rating systems with the aim of measuring sustainability in the built environment, at both individual building and urban district levels. Green building rating systems such as BREEAM (United Kingdom), LEED (United States and Canada), DGNB (Germany) and CASBEE (Japan), are supposed to help consumers determine a building's level of environmental performance. They award credits for optional building features that support green design in categories such as location and building site maintenance, conservation of water, energy, building materials, and occupant comfort and health. The number of credits generally determines the level of achievement.

Environmental rating schemes are gaining increasing popularity at building level among building owners and users. Such procedures may structure the processes of setting the objectives, monitoring the process and assessing the state of buildings using some simple indicators. They are not, however, fully contributing to the objectives of value creation in a knowledge and cooperative society (Lombardi et al., 2010).

At neighbourhood level, the major environmental assessment tools currently in use include the list illustrated in Table 1. However, there are many differences among the current buildings/neighborhood performance assessments tools used in each country, in terms of the levels of performance, the supervisory organizations, the assessment methods, the cost structure, etc.

Table 1. Major environmental assessment tools at neighborhood level

Certification Tool	Year	Country	Certification for Urban Communities
BREEAM	1990	UK	BREEAM – Communities
HQE	1996	France	HQE – Aménagement
LEED	1998	USA	LEED – ND
CASBEE	2001	Japan	CASBEE – UD
Green Star	2002	Australia	Green Star – Communities
DGNB	2009	Germany	DGNB – NSQ

The large number of indicator systems available at present illustrates the important role that indicators and assessment methods play in the study of urban sustainability (Lombardi et al., 2009; Alwaer & Clement-Croome, 2010; Lombardi et al., 2010). However, using indicators as a means for measuring or assessing the sustainability of cities and of practices intended to improve sustainability, is being criticized for several reasons.

One of the main concerns is the way in which indicators are developed (Lombardi et al., 2009). Most present indicators have been developed by governments and intergovernmental bodies in response to their needs. This ensures policy relevance, but often fails to capture what is going on at the grass roots of society. Other indicators have been created by Civil Society Organizations or academics to draw attention to policy issues. Few indicators have been devised by, or are designed for, the real agents of change – businesses and individuals operating at a decentralized level in all societies. The issue of how to reconcile the centralized approaches needed to produce standard comparable indicators and the decentralized nature of most decision making affecting sustainability, has not yet been explored (Lombardi et al., 2009; Lombardi et al., 2010).

A further concern is that many of the indicators reflect the specific interests of their authors, and are not necessarily the product of an empirically-derived understanding of what would constitute sustainability in the particular domain in which the indicator is to be used for assessment (Adams, 2006; Foxon et al., 1999).

Many indicator sets have been assembled, but none has been widely implemented, and their integration to support self-regulating sustainability is still a major challenge. Thus, there is no one recommended indicator set but a number of different approaches that may be appropriate for specific uses. Furthermore, although a process of harmonization of methods and KPIs has been more recently developed at European level in relation to the building scale (CESBA, 2014), this is still a work in progress and currently there is no common international sustainable building assessment.

In relation to the evaluation of smart cities' performance, for instance, a number of ranking systems have been developed. City-rankings (i.e. European Smart Cities Ranking, Smart Cities Hub, Smart Cities Project, etc.) have become a tool for promoting the attractiveness of urban regions over the last twenty years. City-rankings are often used by the cities to sharpen their profile and to improve their position in the competition charts. Although the city-ranking approach is limited by its short-termism and sector-based perspective, city-rankings are not designed to be operative instruments for supporting policy development. Rather, their aim is to "*illustrate differences (…), elaborate perspectives, (…) identify strengths and weaknesses in a comparative way*" (Giffinger et al., 2007).

In the smart city field, there is currently no common framework for cities to analyse such performances, or transfer knowledge of how to be smart in mainstreaming such improvements across the regions. Initial attempts to develop such frameworks have been recorded, for example via Smart City Ranking indices, Future Internet and Triple Helix inspired models of smart city performances, but as yet they represent prototypes around which consensus is to be built as a basis for cooperation between key stakeholders in the smart city community, and for further consolidation of these frameworks as a common set of measures.

Probably the most famous city-ranking index is the one that was developed in 2007 by Giffinger et al., covering seventy medium-sized European cities from a smart city perspective. Lombardi et al. (2012) recently further developed Giffinger's model in connection with a Revised Triple Helix model (Ezkowitz, 2008; Etzkowitz & Zhou 2006), with the aim of investigating the reciprocal relationship between the main agencies in the process of knowledge creation and capitalization: Universities, Industry, Government and Civil Society. Although this model is useful for evaluating and comparing knowledge-based innovation systems and solutions, it is incapable of supporting the whole planning and design process. Therefore, the main question is: "how can a city develop a measure of these actions and how can any improvement in performances along these lines be mainstreamed across the EU?"

According to Alexander (2006), the challenge is to create an evaluation framework that can be "sensitive to the complexity, for transparent communication, enabling effective interaction" as an arena for discussing and resolving conflicting opinions. In the following section, a new framework of trans-scalar indicator data sets will be illustrated. This aims to support and inform the whole project cycle design and management process, involving regeneration stakeholders and, specifically, citizens.

A NEW MULTI-SCALAR APPROACH TO THE EVALUATION OF URBAN PLANNING AND THE BUILT ENVIRONMENT

An urban environment is a complex system that can be represented as a network of interconnected clusters of urban spaces, functions, services, activities, environmental systems and human beings (Batty, 2013). According to Salat (2011), Bourdic et al. (2012), Deakin et al. (2013) and Deakin and Reid (2014), the appropriate spatial scales to be used for describing a urban system are as follows:

1. *City*. This comprehensive scale allows comparisons with other cities, by studying maps of communicating roads and connectivity, and the distribution of roads among users, public transport networks and the connections between different modes of transport. A detailed knowledge of distributions is indispensable to guide public policy.
2. *District*. This scale has to have sufficient aggregated yield data in order to consider the structure, complexity and connectivity of street networks in particular (for pedestrians, bikes, cars, public transport). This scale also makes it possible to examine issues of diversity, whether in terms of social mix (by looking at the diversity of house sizes and prices), of sector mix (the distribution and concentration of different activities), or of the housing and job mix. The perimeters of the district are chosen on the basis of historical and urban criteria. The selection often follows the main arteries and periods of building construction. The form and proportions depend on the grid of the urban fabric. The district often corresponds to a 800 m x 800 m section of a European city, or a 1 mile x 1 mile section of an American city.
3. *Neighbourhood*. The city and district scales focused mostly on connectivity, which loses significance at neighbourhood level, save perhaps for the pedestrian and bicycle grid. Morphology plays a significant role in this scale, as do physical phenomena within the urban fabric: wind speeds and directions, solar potential (sky view factor). These physical parameters are influenced by the form of streets, their orientation in relation

to the sun and dominant winds. This scale corresponds to a 200 m x 200 m section of the French "Haussmann" type of urban fabric, or between 1 and 4 blocks. For an American grid, the appropriate scale will be approximately 400 m x 400 m to maintain the coherence of the urban fabric.

4. *Cluster/block scale*. This scale is particularly interesting in terms of morphological parameters and in urban configurations consisting of adjoining or similar buildings. The perimeter established depends very much on local architecture as well as on the form of, and relationship between, buildings.

The following is a description of the approach adopted when selecting the metrics employed to develop an evaluation system supporting urban planning decisions.

Firstly, a framework is developed for building knowledge and implementing indicators, by revising the following existing approaches:

1. Evaluation tools currently adopted for rating green buildings and the sustainability of urban areas (i.e. BREEAM for Communities, LEED for Neighborhood, DGNB, CASBEE for Urban Development, ITACA Protocol for buildings);
2. Evaluation systems capable of ranking the urban quality and performance of a city (i.e. Smart Cities Ranking by Giffinger et al. (2007), Environment Statistics ISTAT, Matrice della Qualità Urbana AUDIS, Urban Morphology Lab Approach by Salat (2011)).

The final framework provides information about:

- Different types of indicators (qualitative, quantitative, dichotomic);
- A number of spatial scales (building, cluster, neighbourhood, district, city);
- Different stages of project evaluation (brief, design, executive design, implementation, monitoring).

The selected indicators are identified by a code and grouped into homogeneous clusters as follows:

- Urban form (land use, mobility, bio-climate);
- Environment (Water, Biodiversity, Waste, Energy, Local Environmental Quality and Comfort),
- Socio-Economy (Equity, Economy, Culture and Wellbeing)

For instance, in relation to urban form, the following main principles have been used to select appropriate indicators as suggested by Salat (2011), who demonstrated how urban form and urban network structure directly impact on energy & carbon emissions, transportation patterns and infrastructure costs:

1. High density / mixed use. This is useful in order to create a rich network of diversified destinations supporting connections for pedestrians, bicycles and public transport, by creating a strong demand for short-distance travel;
2. A pedestrian and bicycle network. Accessibility inside the district should rely on a pedestrian and bicycle network directly connected to mass transit stations to limit automobile use. Car-free streets enhance the visibility of local commerce;
3. A high density of short connections. Small urban blocks surrounded by a dense network of streets promote greater fluidity and ease of access than huge blocks fed by highways. Worldwide urban textures: Tokyo, Kyoto: 50 m; EU cities: 120 m; Chinese developments: 400-600 m;

4. Public space. Diversified, user-friendly public spaces designed on a human scale are the key to building liveable communities;
5. Self sufficient districts. The design of urban blocks should include systems for generating energy as well as collecting and reusing water and waste;
6. Heterogeneous communities. Sustainable districts should incorporate a wide range of housing types, services and facilities for people with different income levels;
7. The existing conditions of the site. Integrating natural and historic characteristics in new developments for liveable communities
8. The relationship of people to space. The relationship of people to space has to be preserved through the slow, gradual transformation of urban forms.

All the data supporting the adopted metrics derive from open databases contributing towards developing an operative, effective and user-friendly support. Nevertheless, open data are not always updated and may sometimes be obsolete. Furthermore, some indicators are new as they are based on national statistical analysis. The final list includes about 60 indicators, as shown in Figure 2. Table 2 provides a more detailed example of one aspect of the framework, with the illustration of KPIs for Urban Form / Land Use, including the appropriate parameters and their calculation.

The system defines and describes the connections between the various levels of the urban environment. Sustainability is assessed in each city, urban area and cluster of buildings or building, using the appropriate indicators and parameters included in the related spatial scale (see Figure 2 and Table 2).

To facilitate comprehension of this new trans-scalar approach, a few examples from each cluster are provided as follows.

Figure 2. Scheme of the trans-scalar approach and metrics organization
(Source: authors)

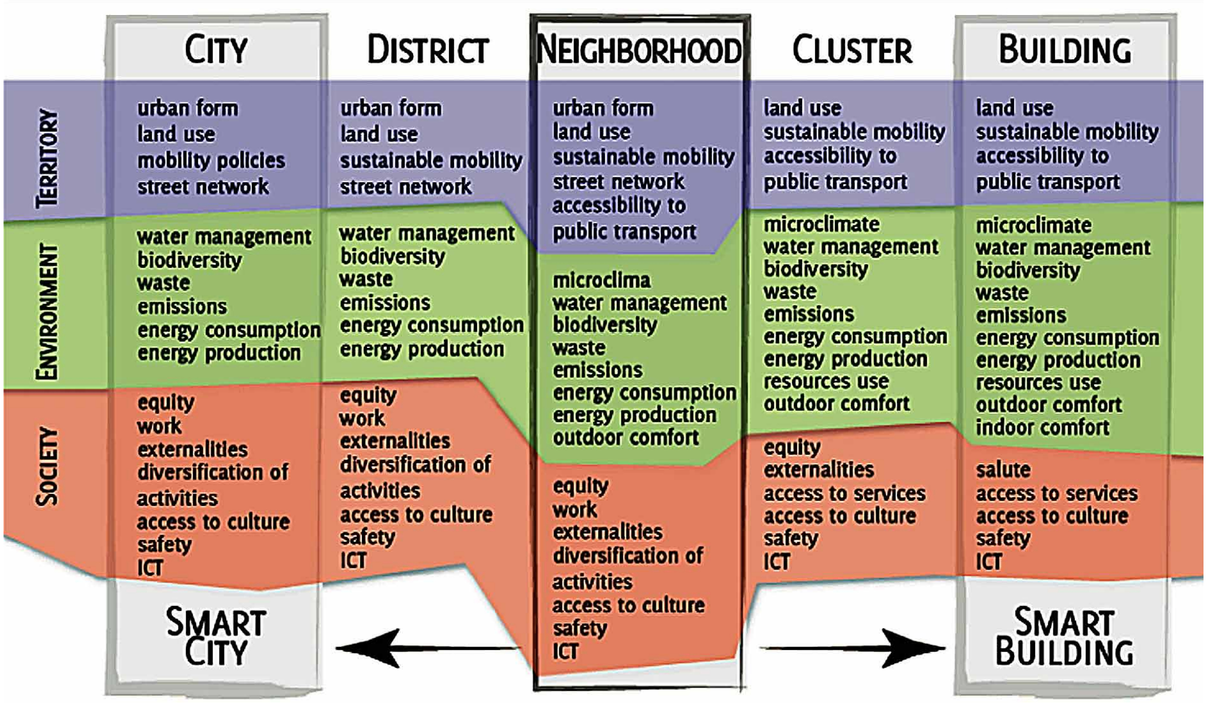


Table 2. Example of the list of indicators used in the new system

Urban Scales/Application Phase			City	District	Neighbourhood	Cluster	Building	Brief Project	Existing Buildings
Urban Form			x	x	x	x	x	x	x
Land Use			x	x	x	x	x	x	x
1	**Development and integration of plot subdivisions**			x	x			x	x
	Intent	Encourage the seamless development of existing blocks, variety and integration in new developments							
	Indicator	Subdivision intensity							
	m.u.	1/m^2							
	Assessment method	No. plot subdivisions / area (m^2)							
2	**Diversity of functions and activities**			x	x			x	x
	Intent	Promote different functions and activities in the area							
	Indicator	Diversity of subdivision size							
	m.u.	-							
	Assessment method	diversity (inverse power law) 1/Cat * S(1...Cat)[1-(Stot,i*S,i^m)/A]^2							
3	**Diversity of land use**			x	x			x	x
	Intent	Facilitate mixed flows and uses							
	Indicator	Diversity of land use							
	m.u.	-							
	Assessment method	diversity 1/Cat * S(1...Cat)[1-S,i/S,i,obj]^2 (road network, built environment, courtyards, green spaces)							
4	**Diversity of the built environment**			x	x			x	x
	Intent	Facilitate mixed flows and uses							
	Indicator	Diversity of subdivision use							
	m.u.	-							
	Assessment method	diversity 1/Cat * S(1...Cat)[1-S,i/S,i,obj]^2 (housing, offices, shops, public facilities, etc.)		x	x			x	x
5	**Preservation of land and soil**			x	x	x	x	x	
	Intent	Reduce land consumption							
	Indicator	Re-use of previously occupied and contaminated land for buildings and infrastructure							
	m.u.	%							
	Assessment method	S(i…Cat)[S,i*weight,i] / S(i…Cat)[S,i] undisturbed land weight = -1 agricultural land weight = 0 occupied land weight = 3 contaminated land weight = 5							

Urban Form: Mobility

Transport lies at the heart of the sustainable urban development issue, and it aims to make the city more compact, to limit urban sprawl, and to reduce the problems and costs of travel (Salat, 2011). At the city level, the protocol transport indicators are mostly related to mobility policies in terms of the connectivity of street networks, for example, while at the district level, metrics focus on the transport grid complexity/distribution and public transport use/availability. The cluster and building level indicators are more specific, as they analyze the dynamics of the connectivity of the pedestrian/bike grid and of bikes facilities such as parking.

Environment: Energy

Energy and sustainability are strictly related. At the city level it is important to compare the complexity of the urban network and the transportation of energy to improve urban efficiency, together with grid management, while at district level, the local production of renewables can be evaluated according to a smart-grid vision. The block scale concerns form and size factor design, as well as the building, with the focus also on energy consumption for heating and cooling purposes.

Urban Form: Economy

A heterogeneous community is diversified in terms of housing types, services and facilities enabling people with different income levels and lifestyles to live together. At the city level, the distribution of each district needs to be evaluated in terms of the global distribution of shops, offices, etc., while the proximity of convenience stores is more suited to the district analysis. The functional mix should also be considered at individual building level, by evaluating the complexity of a building's operation and the flexibility of use by calculating the number of hours it is occupied (as a percentage) over the course of the average day.

The selected indicators were tested on three different urban areas of Turin, Northern Italy. In 2009 Turin joined the Covenant of Mayors, which is the mainstream European movement, involving local and regional authorities, voluntarily pledging to increase energy efficiency and to develop renewable energy sources. Following approval of the Turin Action Plan for Energy (TAPE) presented in Brussels in December 2011, Turin submitted an application to become one of the thirty European Smart Cities. "Torino Smart City" is an ambitious project requiring (*i*) high technology to promote sustainable transport and to reduce greenhouse emissions by more than 40% by the year 2020, and (*ii*) adequate tools and effective methods based on a more integrated urban design and planning approach.

The three typologies of districts used in the testing of this new evaluation system differ according to urban morphology, historical period, road network distribution and housing type (see Figure 3). These are:

- *Old town centre*. This area has remained unchanged for centuries and it allows the indicators' behaviour to be tested within a rooted historical morphologic context, by analysing the efficiency of findings concerning mobility, land use, soil and bio-climate.
- *Spina 3.*This is the last area to be regenerated, recently developed. The urban grid does not follow the regular road network of the town centre, and the blocks are larger.
- *Spina 4.* This is the new development area where urban renewal is currently in progress (see Figure 4). It will be an important hub connecting up the city's main roads, which in the future will determine the north city's accessibility.

As an example, the following indicators are related to mobility, the connectivity of the street network, and equity.

Figure 3. Aerial view of the two districts: historical city centre and Spina 2

Figure 4. Spina 4 new regeneration areas

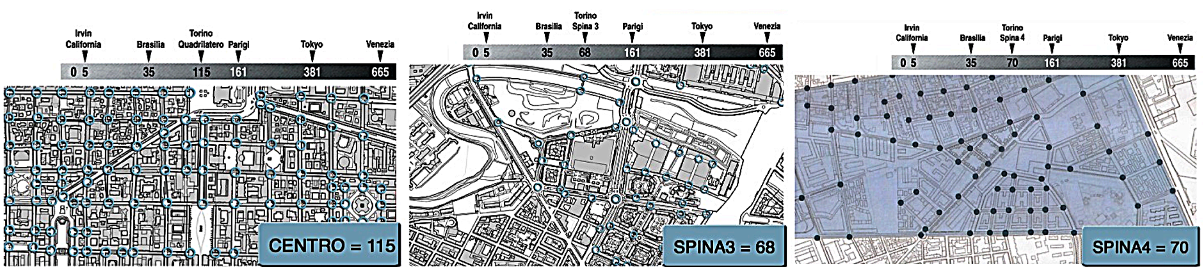
Mobility. Connectivity of the Street Network

The goal of this indicator is to create enough interconnections to multiply the number of possible routes, reduce distances and traffic jams, and make more places easily accessible to pedestrians. The measurement of intersection intensity is possible by quantifying the number of intersections in the streets network. Having numerous intersection points in a street network increases the number of possible routes and serves to reduce distances that need to be covered to get from one point to another. The range varies from 5 for car-oriented cities (Salat, 2011) to over 500 for walkable cities. Figure 5 shows the final scores derived from the tests. These highlight the fact that there are many close intersections (115) in the historical centre, while Spina 3 (68) and Spina 4 (70) have very few.

Mobility. Cyclomatic Number of the Street Network

The cyclomatic number is an indicator of connectivity. It is linked to the number of roads that exist in the district and the city. More roads make for smoother traffic flow. It is measured by calculating the number of primary loops in the network. The greater the number of loops, the greater the number of possible routes into and out of the city. In Paris the number is approximately 80 on the district scale (800x800m). Figure 6 shows the final

Figure 5. Comparison of "connectivity of the street network" findings



scores. Considering that the cyclomatic number in a mixed-used city designed for pedestrians is between 40 and 100 (Salat, 2011), Spina 4 achieved an acceptable score (43), while the city centre has the highest score (81), and Spina 3 the lowest (11).

Equity. Affordability of Housing

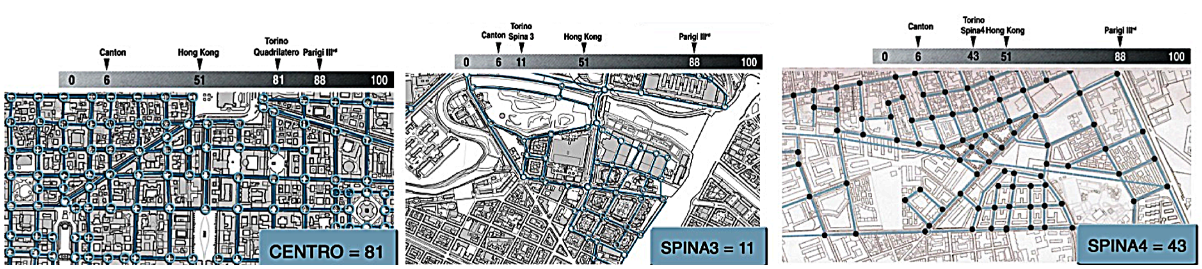
Housing choice is a response to an extremely complex set of economic, social, and psychological impulses. In the United States and Canada, a commonly accepted guideline for housing affordability is a housing cost that does not exceed 30% of a household's gross income. Determining housing affordability is complex, and the commonly-used housing-expenditure-to-income-ratio tool has been challenged. The system evaluates it as the ratio of yearly salary (lowest quintile) to house price per square meter. This enables us to understand how many square meters can be purchased using the lowest quintile of a salary, thus allowing a more realistic comparison to be made between different cities and contexts. The indicator's application to the three urban areas reveals the following: *historical city centre,* 2.47 m^2, *Spina 3,* 3.82 m^2 and *Spina* 4, 4.08 m^2, which indicates that the city centre area is more expensive than the newer areas.

CONCLUSION

With the term "smart city", the European Commission often refers to systemic approaches and organisational innovation, encompassing energy efficiency, low carbon technologies and the smart management of off-peak demand. The maximum untapped innovation potential and maximum environment and societal benefits to be gained are coupled to the integration of Energy, Transport and Information and Communication Technologies (ICT) sectors.

At international level, many evaluation methods and tools have been developed in order to facilitate the integration of environmental values into planning and urban design (de Roo et

Figure 6. Comparison of "cyclomatic number of the street network" findings



al., 2012; Rotmans et al., 2000; Runhaar et al., 2009). These aim to identify and evaluate both the spatial and the technical aspects of the built environment. Although they may help guide the urban planning/design process according to environmental principles, they are not able to deal with all the complex issues involved in a planning design process. Furthermore, these systems are not able to describe urban dynamics at different (closely related) levels using a single, holistic, trans-scalar approach. Most of the current rating systems are conceived as mechanic ex-post evaluation approaches, rather than decisional support for the whole project cycle management process.

The system illustrated in this study is able to assess the sustainability of urban areas, supporting transformation and regeneration processes, as well as decision making, at all major stages of a planning process. It is extremely flexible and suitable for the evaluation at each stage (ex-ante, on-going and ex-post). It is characterized by a trans-scalar approach, and can thus represent all the various different urban dimensions. The trans-scaling feature of the system allows us to describe and evaluate urban complexity moving from the small scale (the building) up to a more extensive scale (the city), and including the cluster size (a few buildings) and the urban district. In this way, all the various interconnections between dimensions are highlighted, as well as the interrelationships between themes and criteria.

The development of this new system has encompassed a number of principles, as follows: sustainability representation; open data and public database use; the clear communication and interpretation of indicators and metrics; the scientific rigor of methods of calculation; the performance quality of urban planning evaluation; trans-scalar flexibility; integration with national laws and standards.

The method has been developed for application to the Italian urban context, and the test carried out in Turin has shown it to be comprehensive, open, accessible, rigorous, well-performing, flexible and appropriate in keeping with the Italian system.

The tool is ready to be adopted by local authorities for the purpose of supporting the regeneration of a strategic urban area called Variante 200 located in the Spina 4 district. The adoption of this system is expected to engender a virtuous effect, ensuring transparent design decisions and involving stakeholders and experts (architects, engineers, etc.) during the design and planning phases.

REFERENCES

Adams, W. M. (2006). The Future of Sustainability: Rethinking Environment and Development in the Twenty-first Century. Retrieved November 30, 2014 from http://cmsdata.iucn.org/downloads/iucn_future_of_sustanability.pdf

Alexander, E. R. (Ed.). (2006). *Evaluation in Planning. Evolution and Prospects*. Aldershot: Ashgate.

Alwaer, H., Bickerton, R., & Kirk, R. D. (2014). Examining the components required for assessing the sustainability of communities in the UK. *Journal of Architectural and Planning Research*, *31*(1).

Alwaer, H., & Clements-Croome, D. J. (2010). Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings. *Building and Environment*, *45*(4), 799–807. doi:10.1016/j.buildenv.2009.08.019

Batty, M. (2013). *The New Science of Cities*. Cambridge: MIT Press.

Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: A new system of cross-scale spatial indicators. *Building Research and Information*, *40*(5), 592–605. doi:10.1080/09613218.2012.703488

Brandon, P. S., & Lombardi, P. (2011). *Evaluating sustainable development in the built environment*. Oxford: Wiley-Blackwell.

Brandt, N., Cambell, F., Deakin, M., Johansson, S., Malmström, M., Mulder, K., . . . Arman, L. (n.d.). *Participation, Indicators and Benchmarking. European Cities Moving Towards Climate Neutrality*. Retrieved November 29, 2014, from http://www.clue-project.eu/getfile.ashx?cid=69201&cc=5&refid=6

CESBA. (2014). *Welcome to CESBA*. Retrieved November 28, 2014, from http://wiki.cesba.eu/wiki/Main_Page

de Roo, G., Visser, J., & Zuidema, C. (2012). *Smart Methods for Environmental Externalities – Urban Planning, Environmental Health and Hygiene in the Netherlands*. Farnham, United Kingdom: Ashgate.

Deakin, M. (Ed.). (2013). *Smart Cities. Governing, modelling and analysing the transition*. London, New York: Routledge.

Deakin, M., & Reid, A. (2014). Sustainable urban development: Use of the environmental assessment methods. *Sustainable Cities and Society*, *10*, 39–48. doi:10.1016/j.scs.2013.04.002

Deakin, M., Reid, A., & Campbell, F. (2013). Demonstrating How Urban Morphology Matters: Reaching Beyond the Geometry of Building Design, Construction Systems and Occupational Behaviours and Towards Broader Context-Specific Transformations. *Environmental Management and Sustainable Development*, *2*(2), 101–121. doi:10.5296/emsd.v2i2.4307

Ezkowitz, H. (2008). *The triple helix: university, industry and government*. London: Routledge. doi:10.4324/9780203929605

Ezkowitz, H., & Zhou, C. (2006). Triple Helix twins: Innovation and sustainability. *Science & Public Policy*, *33*(1), 77–83. doi:10.3152/147154306781779154

Foxon, T. J., Leach, M., Butler, D., Dawes, J., Hutchinson, D., Pearson, P., & Rose, D. (1999). Useful Indicators of urban sustainability: Some methodological issues. *Local Environment*, *4*(2), 137–149. doi:10.1080/13549839908725589

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., & Meijers, E. (2007). *Smart cities. Ranking of European medium-sized cities. Vienna: Centre of Regional Science, Vienna UT*. Retrieved March 13, 2013, from www.smartcities.eu

Joint Programming Initiative. (2010). *URBAN EUROPE: Global Challenges – Local Solutions, presented by Austrian Ministry of Science and Research, Austrian Ministry of Transport, Innovation and Technology, Dutch Ministry of Transport, Public Work and Water Management*. Retrieved March, 16, 2010, from http://www.eurosfaire.prd.fr/7pc/doc/1300116345_jpi_urbaneurope_16_03_2010.pdf

Lombardi, P., Cooper, I., Paskaleva, K., & Deakin, M. (2009). The challenge of designing user-centric e-services: European dimensions. In C. Reddick (Ed.), *Strategies for local e-government adoption and implementation: comparative studies*. Hershey, PA: Idea Group Publishing. doi:10.4018/978-1-60566-282-4.ch024

Lombardi, P., Giordano, S., Caragliu, A., Del Bo, C., Deakin, D., Nijkamp, P., & Farouh, H. et al. (2012). An Advanced Triple-Helix Network Model for Smart Cities Performance. In O. Y. Ercoskun (Ed.), *Green and Ecological Technologies for Urban Planning: Creating Smart Cities*. Hershey, PA: Information Science Publishing. doi:10.4018/978-1-61350-453-6.ch004

Lombardi, P., Huovila, P., & Niitamo, V.-P. (2010). Metrics for Value Creation in a Sustainable Knowledge Society. In *Proceeding of World Building Congress* (pp. 28-38).

OECD. (2011). *Urban Environmental Indicators for Green Cities: A tentative indicator set, Working Party on Environmental Indicators*. Paris, France: OECD.

OECD. (2012). *Redefining "Urban": a new way to measure metropolitan areas*. Paris, France: OECD.

Rees, W. E. (1997). Is 'sustainable city' an Oxymoron? *Local Environment: The International Journal of Justice and Sustainability*, *2*(3), 303–310. doi:10.1080/13549839708725535

Roberts, P., & Hughes, S. (2006). *Urban Regeneration: a handbook*. London: Sage Publications.

Rotmans, J., Van Asselt, M., & Vellinga, P. (2000). An Integrated Planning Tool for Sustainable cities. *Environmental Impact Assessment Review*, *20*(3), 265–276. doi:10.1016/S0195-9255(00)00039-1

Runhaar, H., Driessen, P. P. J., & Soer, L. (2009). Sustainable urban development and the challenge of policy integration: An assessment of planning tools for integrating spatial and environmental planning in the Netherlands. *Environment & Planning B*, *36*(3), 417–431. doi:10.1068/b34052

Salat, S. (2011). *Cities and Form: on sustainable urbanism*. Paris, France: Hermann.

United Nations. (2007). Indicators of sustainable development: Guidelines and methodologies. Retrieved November, 30, 2014, from http://www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf

United Nations Human Settlements Programme. (2004). *Urban Indicators Guidelines: Monitoring the Habitat Agenda and the Millennium Development Goals.* Retrieved November, 30, 2014, from http://ww2.unhabitat.org/programmes/guo/documents/urban_indicators_guidelines.pdf

United Nations Human Settlements Programme. (2006). *State of the World's Cities 2006/7. The Millennium Development Goals and Urban Sustainability: 30 Years of Shaping the Habitat Agenda*. Retrieved November, 30, 2014 from http://sustainabledevelopment.un.org/content/documents/11292101_alt.pdf

Veirier, L. (2008). *Historic districts for all: a social and human approach for sustainable revitalization*. Retrieved November, 30, 2014, from http://unesdoc.unesco.org/images/0017/001784/178420e.pdf

KEY TERMS AND DEFINITIONS

Assessment Tools: Systems or methodologies used for evaluating activities, goods, issues, processes, projects, products and everything which required a value judgements.

Built Environment: A material, spatial and cultural product of human labor that combines physical elements and energy in forms for living, working and playing (en.wikipedia.org/wiki/Built_environment).

Energy Transition: A process of change from a socio-economic system strongly based on fossil fuel toward a low carbon or a post carbon one.

Metrics: Parameters or measures of quantitative assessment used for measurement, comparison or to track performance or production (www.investopedia.com/terms/m/metrics.asp).

Performance Indicators: A performance indicator or a key performance indicator (KPI) is a type of performance measurement which is used to evaluate the success of a particular activity in which it engages (adapted from en.wikipedia.org/wiki/Performance_indicator).

Smart City: A city based on the concepts of knowledge society, competitiveness and sustainable development.

Sustainable Development: A development that meet the needs of present generation without undermining the meets of future generation.

Section 2

Smart Citizens and Governance

Chapter 4
Smart Cities:
A Salad Bowl of Citizens, ICT, and Environment

Elsa Negre
Paris-Dauphine University, France

Camille Rosenthal-Sabroux
Paris-Dauphine University, France

ABSTRACT

Smart City is a fuzzy concept that has not been clearly defined either in theoretical studies or in empirical projects. Smart Cities are based on Information and Communication Technologies (ICT), people (with their knowledge, habits, experiences, culture and behaviour) remain at the heart of concerns. In this chapter we are interested in the centrality of citizens (i.e. in the heart of the city) and of ICT in their environment. This leads us to take into account the tacit knowledge brought by citizens and the knowledge that may be divulged through ICT. We then present the concept of the Information and Knowledge System (IKS), and then we explain how it differs from that of the Digital Information System (DIS). We also point to the role of ICT in the DIS, and to their impact on improving the smartness of cities.

INTRODUCTION

Since the early 1990s, the development of Internet and communication technologies has facilitated actions designed to create opportunities for communication and information sharing by local authorities. This phenomenon first appeared in the United States before moving across the globe to Europe and Asia. Indeed, in our everyday lives we are increasingly overwhelmed by data and information. This constant flow of data and information is often the result of Information and Communication Technologies (ICT). Moreover, the potentialities of ICT, that have increased almost exponentially, have given rise to a huge mass of data to be processed (Batty, 2013). We live in an increasingly digital world, and people are beginning to feel the effects of these changes. Cities need to be closer to their citizens (Bettencourt, 2013).

DOI: 10.4018/978-1-4666-8282-5.ch004

Today's world faces two important forms of growth: the growth of urbanization, and the rise of information technologies, meaning that digital infrastructures infer an information environment that is "*as imperceptible to us as water is to a fish*" (McLuhan & Gordon, 2011).

As pointed out by Lima (2011),

The complexity of connectedness of modern times requires new tools of analysis and exploration, but above all it demands a new way of thinking. It demands a pluralistic understanding of the world that is able to envision the widen structural plan and at the same time examine the intricate mesh of connections among its smallest elements. It ultimately calls for a holistic systems approach; it calls for network thinking.

There is a kind of parallelism between technologies and humans. On the one hand, people increasingly use technologies and are now hyper-connected, while on the other hand, (numeric) systems are increasingly user-centered (Viitanen & Kingston, 2014). Thus, within cities, systems have to adapt to hyper-connected citizens, in a very specific environment, namely that of cities in constant evolution where systems and humans are nested.

The advent of new technologies also means that the city is now faced with a massive influx of data (Big Data) from heterogeneous sources including social networks. It is also important to note that much information and / or knowledge flows between different people (with different purposes and backgrounds) and between different stakeholders (Kennedy, 2012). In this respect, the city sees numerous data circulate via the internet, wireless communication, mobile phones,…

Being "*smart*" is an increasingly important challenge for many cities and communities. This is of particular interest within the domain of ICT, and for such systems where economic, social, and other issues prevail. Giffinger et al. (2007) propose a ranking of 70 European medium-sized cities by using 6 characteristics. In fact, for Giffinger et al. (2007),

A Smart City is a city well performing in a forward-looking way in these six characteristics, built on the "smart" combination of endowments and activities of self-decisive, independent and aware citizens. […] Each characteristic is therefore defined by a number of factors. Furthermore, each factor is described by a number of indicators. […] Finally 33 factors were chosen to describe the 6 characteristics:

Smart economy (competitiveness, including innovation, entrepreneurship, trademarks, productivity, flexibility, international embeddedness and ability to transform), smart governance (participation, including participation in decision making, public and social services, transparent governance, and political strategies and perspectives), smart environment (natural resources, including attractivity of natural conditions, pollution, environmental protection and sustainable resource management), smart people (social and human capital, including level of qualification, affinity to lifelong learning, social and ethnic plurality, flexibility, creativity, cosmopolitanism/ open mindedness and participation in public life), smart mobility (transport and ICT, including local accessibility, inter-national accessibility, availability of ICT-infrastructure, sustainable, innovative and safe transport systems), smart living (quality of life, including cultural facilities, health conditions, individual safety, housing quality, educational facilities, tourist appeal and social cohesion). These are the six characteristics and factors that form the framework for the indicators and assessment of a city's performance as a smart city. The indicators that "*describe the factors of a smart city are derived from public and freely available data*" (Giffinger et al., 2007).

However, it should be pointed out that smart cities consist of multi-level stakeholders. It is difficult to give an exhaustive list of all stakeholders involved, but they include, for example, local communities, citizens, local governments, environment, culture, non-governmental organizations, ICT, and so on.

The definition of a smart city is indispensable when trying to establish its perimeter and to understand which actions and ventures can be considered smart, and which cannot. Moreover, a standard definition is also the first step for a city towards specifying its own vision of a smart city strategy. The definition of smart city, and a comprehensive smart city framework, are the essential building blocks of a smart city goals system.

AlAwadhi and Scholl (2013) indicate that the definition of smart city depends on the practitioners involved, which is why a huge number of (different) definitions exists. In this chapter, following Caragliu et al. (2011), *w*e shall consider that Cities are Smart*:*

…when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.

It is also important to note that much information and / or knowledge flows between different people (with different purposes and backgrounds …) and between different stakeholders.

The city sees vast quantities of data circulating via the Internet, wireless communication, mobile phones, etc.; generating so much data requires adequate tools. For example, Kennedy (2012) indicates that Big Data can be seen as a proxy for the city where "*infomass*" intersects with "*biomass*" (Mitchell, 1999).

Faced with such rapid changes resulting from the globalization of markets, the liberalizing of the economy and the impact of ICT, many organizations have become aware of the value of non-material capital, and more specifically of intellectual capital. In the new economy that is emerging, there is increasing freedom of action for a growing number of individuals, regardless of their positions and roles: they are placed in situations where decisions need to be made. By analogy, in a city all citizens become knowledge-citizens, especially those whose knowledge is the crucial factor enabling them to improve their decision-making abilities. Knowledge is valuable because ultimately it enables better decisions and actions to be taken (Grundstein et al., 2003; Simon, 1969).

This chapter is organized as follows: we present the related work on tacit and explicit knowledge, Data-Information-Knowledge, and the link between smart cities and information systems. We then propose an analogy with a salad recipe complete with ingredients and dressing: in other words, the recipe, ingredients and dressing for a smart city.

RELATED WORK

In this section we detail certain studies of smart cities, tacit and explicit knowledge, and information systems. It should be pointed out that we find ourselves in a multi-organizational, multi-stakeholder context. To the best of our knowledge, no studies have been conducted yet within such a context. This is why we have had to base our observations on studies carried out within a company context, i.e. a mono-organizational setting sometimes featuring multiple stakeholders.

Tacit and Explicit Forms of Knowledge

We suggest an approach to Digital Information Systems (DIS) centred on the Information and

Knowledge that people possess, in order to improve decision-making processes and enhance the added-value of business processes within the city. Information and Communication Technology (ICT) is an indispensable part of our modern World. Global economies are becoming increasingly dependent on technology, and the requirements of such technology and of society are increasingly larger, more complex, more widespread and more important.

ICT allows people situated outside a city to communicate with other people and to exchange ideas and knowledge. Such observations concerning knowledge within the city context, highlight the importance of tacit knowledge. They reveal an interest in creating a favourable climate for both the exchange and the sharing of tacit knowledge, and for its transformation into explicit knowledge, thus extending the field of knowledge coming under the rules and regulations governing industrial property. Moreover, we should emphasize the fact that capitalizing on a city's knowledge is an ongoing issue, and one that is omnipresent in everyone's activities, and as such it should have an increasing impact on a city's management functions.

A company's knowledge consists of tangible elements (databases, procedures, drawings, models, algorithms, documents used for analysing and synthesizing data) and intangible elements (people's abilities, professional know-how, "*trade secrets*", "*routines*" – unwritten rules of individual and collective behaviour patterns (Nelson & Winter, 1982) –, knowledge of the company's history and decision-making situations, knowledge of the company environment (clients, competitors, technologies, influential socio-economic factors)) (Grundstein et al., 2003). These elements characterize a company's ability to design, produce, sell and support its products and services. They are representative of the company's experience and culture (Davenport & Prusak, 1998). They constitute and produce the added-value of its organizational and production business processes.

Tangible elements are "*explicit knowledge*". Heterogeneous, incomplete or redundant, such knowledge is often characterized by the circumstances under which it was created. These elements do not express the unwritten rules of those who formalize knowledge – the "*unspoken words*". They are stored and scattered in archives, filing cabinets and databases.

Intangible elements are "*tacit knowledge*". Acquired through practice, this form of knowledge is adaptable to the contingent situation. Whether explicitable or non-explicitable, such knowledge is often transmitted through an implicit collective apprenticeship or a master-apprentice relationship. It is located in people's minds.

Here we are referring to the knowledge classification of Polanyi (1967). He divides human knowledge into two categories: tacit knowledge and explicit knowledge. "*Tacit knowledge is personal, context-specific, and therefore hard to formalize and communicate. Explicit or 'codified' knowledge, on the other hand, refers to knowledge that is transmittable in formal, systematic language*" (Polanyi, 1967). Our point of view can be found in the work of Nonaka and Takeuchi (1995) where the authors, with reference to Polanyi (1967), consider that "*tacit knowledge and explicit knowledge are not totally separated but mutually complementary entities*" (Nonaka & Takeuchi, 1995). For Nonaka and Takeuchi (1995), explicit knowledge can be easily expressed in written documents but is less likely to result in major decisions than tacit knowledge is, which is to say that the decisional process stems from knowledge acquired through experience, even though it may be difficult to express in words.

These observations concerning knowledge in the company context highlight the importance of tacit knowledge. They point out the interest in taking into account tacit knowledge in decision process. By analogy, in smart cities context and more generally, in cities context, there exist tacit knowledge and explicit knowledge.

Data, Information, and Knowledge

Many people associate the terms Knowledge Management (KM) and Information System (IS) with some kind of technological system. This is very often reduced to simple IT-based systems, which offer basic functions for the sharing of documents and information among the employees of the company. It is based on the incorrect assumption that knowledge can be gathered and managed in the same manner as information – i.e. that it can be processed, transferred and stored. Knowledge can very often be mistaken for information. What is the difference then? In the following, we are going to examine the differences between the concepts of data, information and knowledge. Finally, we shall present an empirical model of the DITEK (Data, Information, Individual's Tacit and Explicit Knowledge) process which illustrates the transformation from one to another, and its formalization.

Numerous authors have analysed the notions of data, information and knowledge, notably Polanyi (1967), Tsuchiya (1993), Newell et al. (2000) and Walsham (2001).

Furthermore, Wilson (2002) offers the following synthesis:

The developing practice of knowledge management has seen two different approaches to definition; one arises from information management and sees knowledge as some higher-level order of information, often expressed as a triangle progressing from data, through information and knowledge, to the apex of wisdom. Knowledge here is seen as a thing or entity that can be managed and distributed through advanced use of technology… The second approach sees the problem from a sociological basis. These definitions see knowledge as a human capability to act (Wilson, 2002).

The dominant positivism approach of KM is implicit in the DIKW (Data-Information-Knowledge-Wisdom) hierarchy model. This model has led to numerous computer and information studies. For example, Polanyi (1958) re-appraised the DIKW hierarchy by examining the postulation of the hierarchy in a number of widely-read textbooks in the field of information systems and knowledge management, mostly published in 2003 and later, and noted that

… there is a consensus that data, information and knowledge are to be defined in terms of one another, although data and information can both act as inputs to knowledge; the tangle of concepts can be explored at two levels – the relationship between data and information, and the relationship between information and knowledge" (Polanyi, 1958) and she raised the question: "Is there a sharp divide between data, information and knowledge, or do they lie on a continuum with different levels of meaning, structure and actionability occurring at different levels? (Polanyi, 1958).

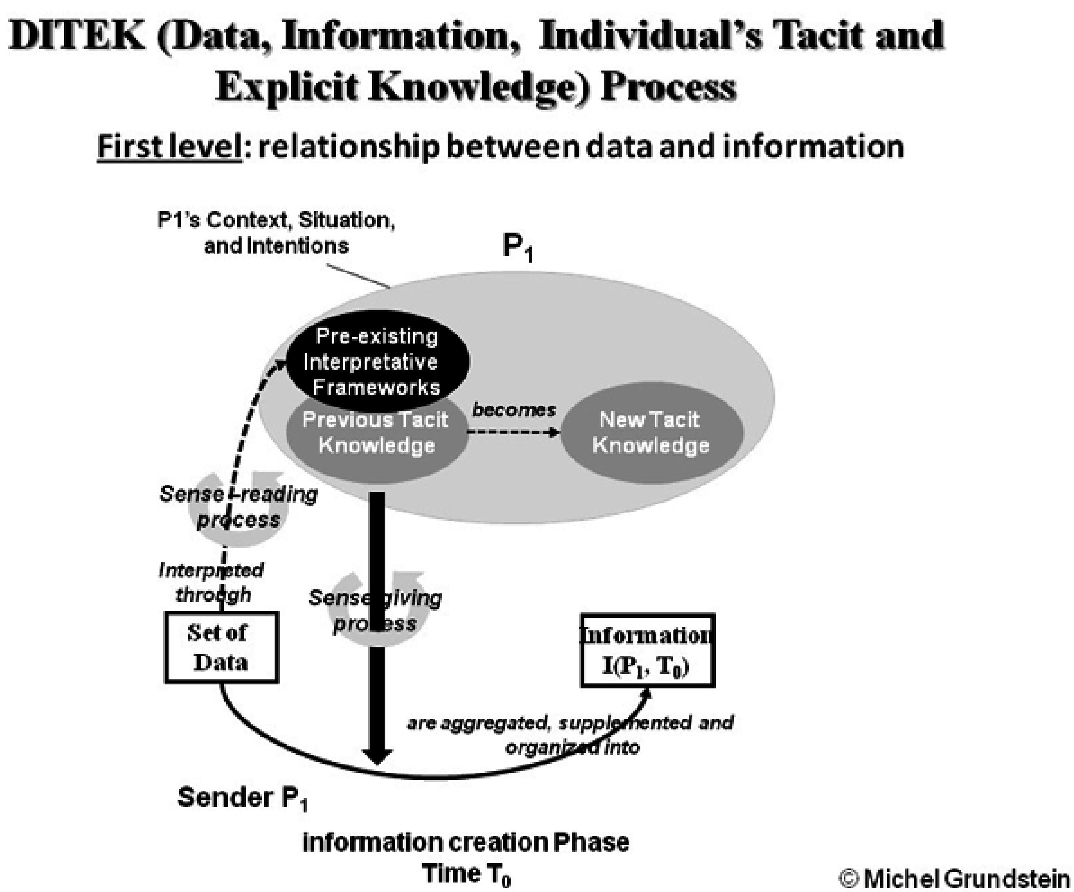
Despite all of these studies, we have to focus our thoughts within the context in which the notions of data, information and knowledge are used: in our case, this is the field of business enterprises, and more generally that of organizations. This leads us to an understanding of the transformation process, via the construction of the DITEK empirical model described below.

From data to information, and to tacit and explicit knowledge: the DITEK process model Based on the theories and assumptions set out above, we have elaborated a model that attempts to describe the process of transformation from data to information, and from information to tacit and explicit knowledge. This model, called the DITEK process model (Nonaka & Takeuchi, 1995), describes the relationship between data and information on one level, and the relationship between information and tacit and explicit knowledge on a second level. Unlike the idea of a continuum existing between the concepts of data, information and knowledge based on the DIKW hierarchical model, the DITEK process model reveals the discontinuity between these concepts. The DITEK model, by analogy with the mental model (Mc Dermott, 1999), emphasises the function of the interpretative framework as a filter that provides the mechanism through which data aggregated into new information, are filtered and processed by an individual's tacit knowledge.

1) The first level: from data to information. Initially we have to consider the relationship between data and information. This first level must be thought of as a basic process in which data are discrete, raw elements perceived, gathered and filtered by a person before being aggregated, supplemented and organized into information. Let us now describe this transformation process (see Figure 1).

At time T_0, sender P_1 is acting in a specific context and situation. P_1 possesses pre-existing interpretative frameworks, previous tacit knowledge, and given intentions. During an information creation phase, P_1 has direct access to a set of external data. Subsequently, P_1, according to a sense-reading process that is dependent upon his pre-existing interpretative frameworks, which in turn are activated depending on the context, his situation and his intentions, filters some of these data that make sense to him. At the same time, a sense-giving process using P_1's previous tacit knowledge enables P_1 to aggregate, supplement and organize selected data into information I (P_1,T_0). Once created, this information becomes a static object separate from P_1 and independent

Figure 1. DITEK process model level 1: from data… to information



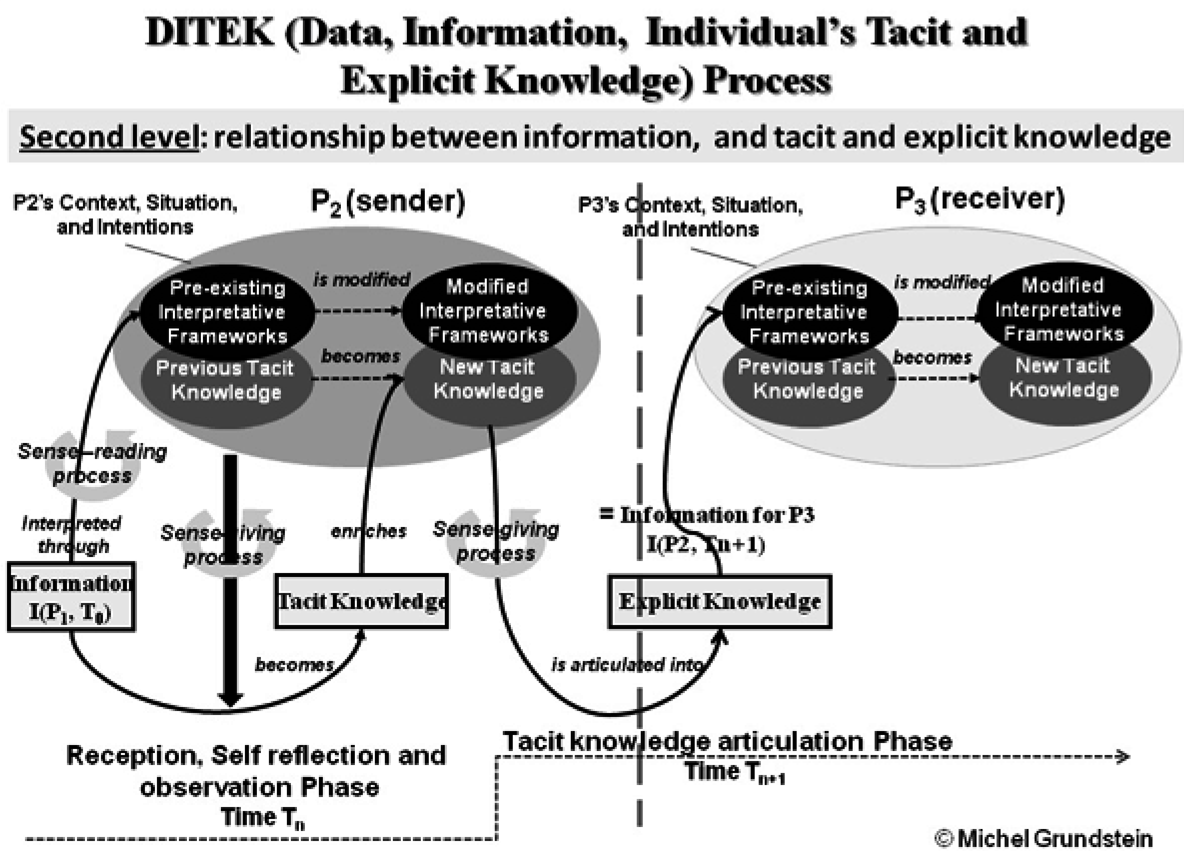
of time. It is this information that is passed-on by individuals, or by the Digital Information System (DIS) where it is stored, treated and transmitted as a stream of digital data. During this process, P_1's pre-existing interpretative frameworks remain unchanged; previous tacit knowledge can be reorganized and modified into new tacit knowledge.

2) The second level: from information to tacit and explicit knowledge: At a second level, we have to consider the relationship between information and tacit and explicit knowledge.

This level marks a break with the first level, since it presupposes that information already exists regardless of the time and context in which it was created. Let us now describe this process of transformation (see Figure 2).

At time T_n representing a later stage of the first-level process, when P_2 perceives the information I (P_1,T_0) during a phase of reception, self-reflection and observation, this information is gathered by P_2, who finds himself in a different context and situation than P_1 who has processed it. P_2 has his own intentions. Subsequently, P_2 interprets this information by means of a sense-reading process, by filtering data through those pre-existing interpretative frameworks activated subject to his context, situation and intentions. At the same time, a sense-giving process using P_2's previous

Figure 2. DITEK process model level 2: from information… to tacit and explicit knowledge



knowledge comes into operation and engenders new tacit knowledge. In this way P_2's pre-existing interpretative frameworks change, and P_2's previous tacit knowledge is enriched, enabling P_2 to understand his situation, identify a problem, find a solution, decide and act. The results of this process are modified interpretative frameworks and new tacit knowledge. The process of transformation of information into tacit knowledge is a process of knowledge construction.

Created knowledge can vary enormously from one individual to another when the commensurability of their interpretative frameworks is limited, regardless of the reasons for this. There is a substantial chance that the same information will make different sense to each of them, and consequently generate the construction of different tacit knowledge in the minds of those with a stake in the decision-making process. Unlike information, knowledge is dynamic. Once constructed it cannot be considered as an object independent of the individual who built it, or the individual who appropriates it to make a decision and to act. Later on, at time T_{n+1}, when P_2 as a sender communicates with receiver P_3, during the articulation of tacit knowledge, a sense-giving process enables P_2 to transform a part of his new tacit knowledge into explicit knowledge that is no more than information I (P_2,T_{n+1}) for P_3.

As a result, one can understand the importance of clearly distinguishing static factual information which enables us to identify and describe the context and situation in which a problem arises, from the cognitive process engendered by the interpretative frameworks and the tacit knowledge possessed by the individual who processes this information to learn and to obtain the knowledge he needs to carry out his tasks. Consequently, paraphrasing Chua and Brennan (2004) if technology offers the possibility of making information available across time and space, we always have to bear in mind the role of the individual in the knowledge-sharing process, while also paying attention to how individuals use technology to share knowledge. Our KM approach leads us to consider tacit and explicit knowledge as the outcome of a sense-giving process involving people engaged in actions. It mainly depends on the economic, strategic, organizational, socio-cultural and technological contexts.

In a Smart City context, Kennedy (2012) proposes to use the difference between data, information and knowledge, by employing the Data-Information-Knowledge (DIK) continuum (Masud et al., 2010) to transform data into knowledge for data visualisation.

From our point of view, tacit knowledge is per se linked to human beings. Given that citizens are key to our approach, we have introduced the concept of the "knowledge-citizen" since we believe citizens to be bearers of tacit knowledge.

THE INFORMATION AND KNOWLEDGE SYSTEM AND THE DIGITAL INFORMATION SYSTEM

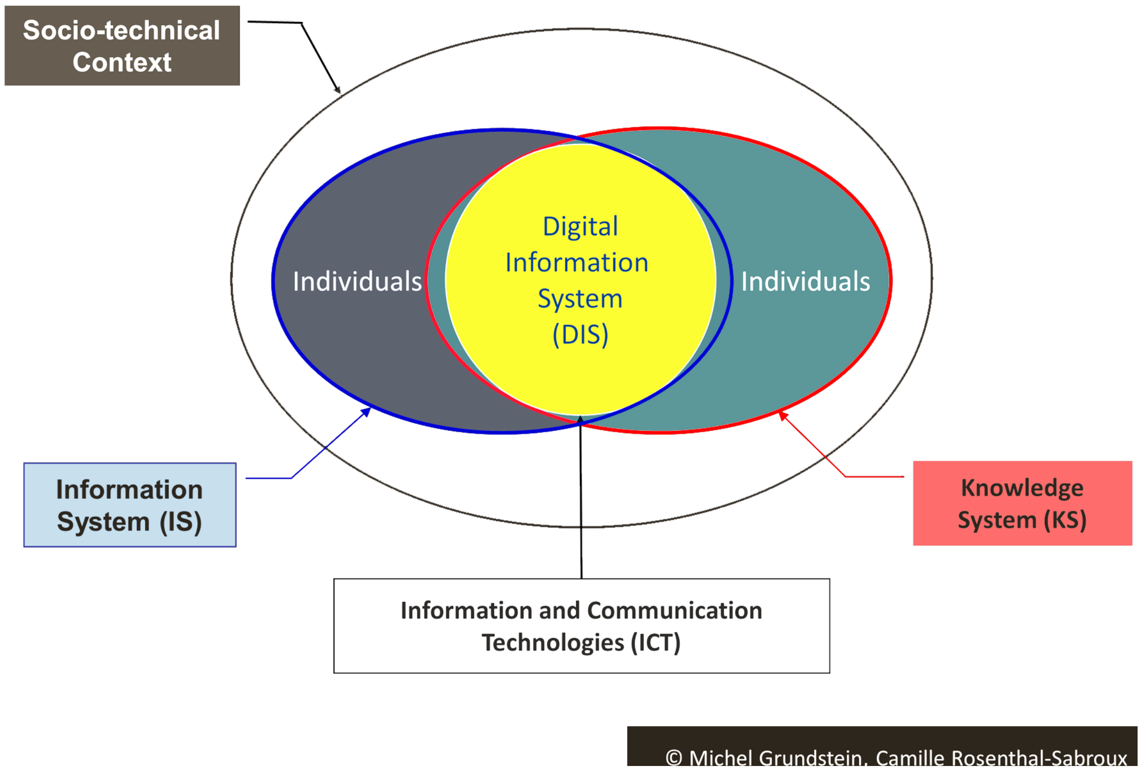
In this section, we will present the Information and Knowledge System (IKS) concept (Figure 3) and the Digital Information System (DIS).

Many authors have already defined the concept of Information System. The following are just some of such definitions:

An Information System is an organized set of resources: material, software, employees, data, procedures, in order to acquire, to process, to store, to disseminate information (data, documents, image, sound, etc.) in organization, translated from (Reix, 2000).

An Information System is the set of all elements that contribute to the process and the circulation of information in an organization (data base, software, procedures, documents) including Information Technology, translated from (Educnet, 2006).

Figure 3. Information and knowledge system



Technically, we can define an Information System as a set of elements interconnected which collect (or recover), process, store and disseminate information in order to support decision and process control in organization (Laudon & Laudon, 2000).

Information System is an organized set of technological and human resources which aim is to enhance the activities of the organization, translated from (Nurcam & Rolland, 2006).

For us, the information system is composed of two dimensions.

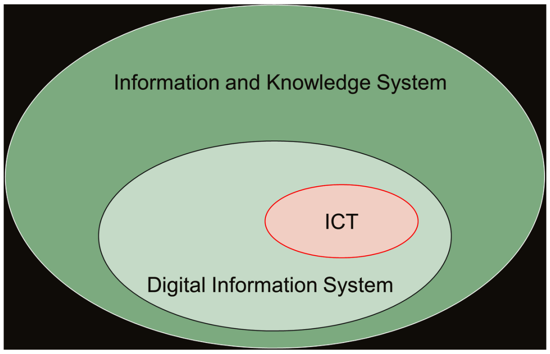
- The Organizational Dimension: humans and tools who can collect, process, store and divulge information in order to support decisions and control processes.
- The Technical Dimension: artificial objects, artefacts, man made. The DIS that collects, processes, stores and divulges information and knowledge in order to support decisions and control processes.

The concept of IKS takes into account the potentialities of Information and Communication Technologies (ICT).

For us, ICT fall within the perimeter of Information Systems, that is, ICT are a part of Information Systems (see Figure 4) and thus ICT are, de facto, a part of the DIS.

Information and Knowledge Systems (IKS) are supported by Digital Information Systems (DIS). DIS are the source of, and provide support for, decisional and monitoring processes. DIS structure and mould a new organization's processes. DIS have new functions that generate new uses and new forms of behaviour that are very different from the requirements analysed at the beginning of the design process.

Figure 4. IKS, DIS, and ICT



Depending on the design, models and technical tools used when DIS are implemented, this phenomena is a factor leading to organizational innovation. Consequently, value-adding processes are created and modified as described by Porter (1979). These developments in turn generate new problems and needs. On the one hand, the understanding and resolution of problems leads to the construction of new knowledge; on the other hand, the new requirements lead to the design of new functionalities. The IKS must take these developments into account.

The Value-Adding Processes

Value-adding processes represent the organizational context in which knowledge is an essential factor of performance. It is within this context that a KM initiative is implanted. As Tonchia and Tramontano (2004) have pointed out: "*Process Management, with the concepts of internal customers and process ownership, is becoming one of the most important competitive weapons for firms and can determine a strategic change in the way business is carried out*". These authors specify that: "*Process Management consists in the rationalization of processes, the quest for efficiency/effectiveness, a sort of simplification/clarification brought about by common-sense engineering*". As Process Management engenders structural changes, when performing Business Process Reengineering we should consider KM activities in order to identify knowledge that is essential to enabling value-added processes to effectively achieve their goals (Figure 5).

Digital Information Systems, ICT, and Smart Cities

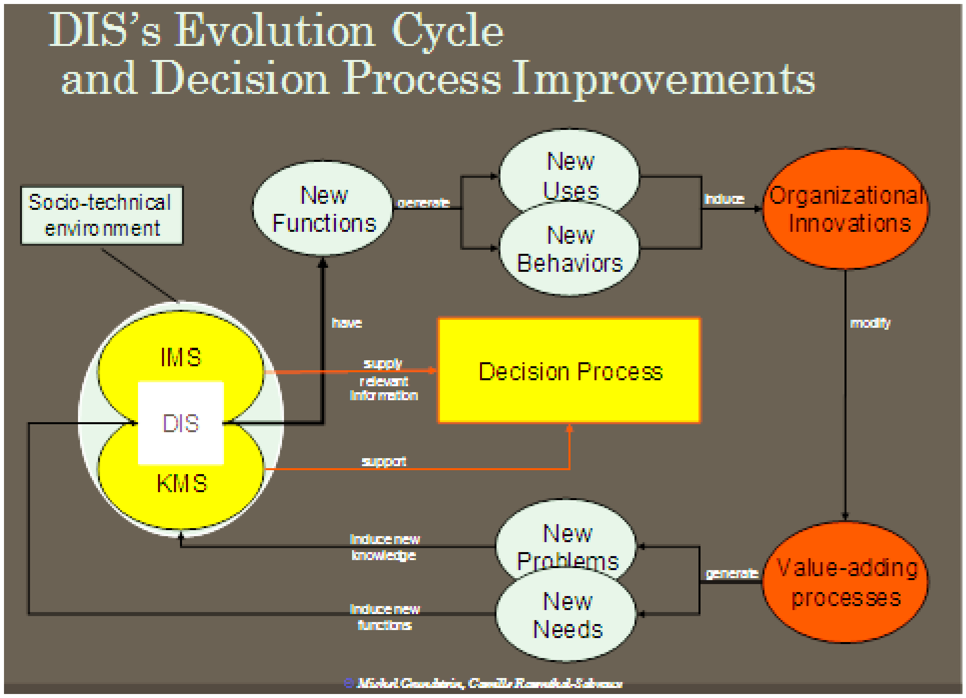
The use of Information and Communication Technology (ICT) is a very important ingredient of smart cities. According to Ferro et al. (2013), "*in the smart city house*" model, "*ICT offers to create value and transform cities into smarter, more sustainable environments*". ICT also provides an important contribution in terms of the management, planning and control of production, to both energy "*prosumers*" and energy network operators. The second contribution of ICT, according to Ferro et al., once again, is the possibility to transform the way in which many daily activities are conducted. And finally, the role of ICT is very important in informing individual choices and behaviour. From our point of view, as detailed in (Dameri et al., 2014; Dameri & Rosenthal-Sabroux, 2014), ICT constitutes the heart of the smart city.

A SALAD RECIPE

By analogy with a salad recipe complete with ingredients and dressing, this section indicates the ingredients and dressing of a smart city.

Note that energy efficiency and open innovation are the basis of the smart city concept (AMETIC, 2013; Chesbrough, 2003; Chesbrough & 2006). The advent of ICT opens up new possibilities to transform governance and redefine the interaction of the various city stakeholders (Chan, 2013; Pyrozhenko, 2011; Almirall & Wareham, 2008; Schaffers et al., 2011). Urban planning, urban development (Trivellato et al., 2013) and smart growth from the urban planners'

Figure 5. The digital information system and the decision process



point of view (Ferro et al., 2013; Anthopoulos & Vakali, 2012; Fernback, 2010) has also contributed towards the development of smart cities. Furthermore, technology will enable urban planners, for example, to better shape our cities (Townsend, 2013; Wang et al., 2007).

Ingredients

In the literature, Chourabi et al. (2012) propose 8 critical factors for a smart city framework, which may be seen as the 8 ingredients in our recipe (namely, People communities, Economy, Governance, Natural Environment, Built infrastructure, Policy, Organisation, and Technology), whereas Nam and Pardo (2011) propose just 3 ingredients. From our point of view, smart cities are multi-stakeholders. So, we have an undefined number of ingredients. In fact, the ingredients you put into the salad give it a special taste. Different ingredients produce different tastes, and therefore a different type of smart city.

The smart city consists of the:

- Citizens
- Information and Communication Technology (ICT)
- Environment
- Transportation
- Administration
- Government and e-government
- Urban planners of the city in question and of other cities.

Dressing

What we call the dressing consists of everything that flows and transits within the city and to and from other stakeholders (other cities ...), and how this is managed and organized.

It comprises:

- Tacit knowledge
- Explicit knowledge

- Data
- Information.

Recipe

Based on what we said previously, the smart city owns an Information and Knowledge System (IKS) which contains a digital component, the Digital Information System (DIS), which permits the city to be qualified as a "digital city".

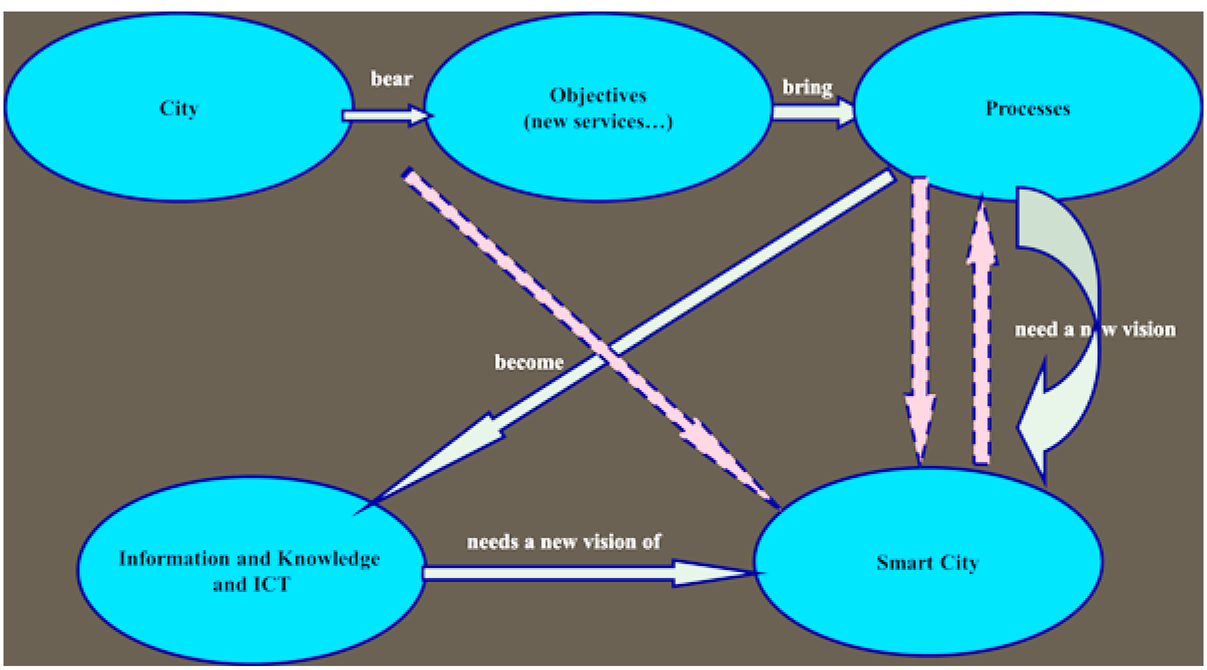
We propose a definition of digital city adapted from Ishida et al. (2002) where cities are digital:

… when investments are made in Information and Communication Technologies (ICT) and communication infrastructure in which people in regional and national communities can interact and share information, knowledge, experiences, and mutual interests. The Digital City integrates urban information (both achievable and real time) and creates public spaces on the Internet for people living in/visiting the city.

Thus, nowadays the concept of smart city is absorbing that of the digital city, although these two different urban strategies need different processes and practices to be implemented successfully and to achieve the best results. For this reason, even if they actually merge into a unique city plan, they should be implemented taking into consideration their different natures. The following elements have emerged from a survey: ICT bears functionalities, functionalities imply new uses, and these new uses lead to the reorganisation of cities. This new vision leads to the "*Smart City*" (see Figure 6).

A city may have new objectives, such as new services or improving on its degree of "smartness" (Negre & Rosenthal-Sabroux, 2014) by, for example, deciding to further develop public transportation systems (display waiting times at bus stops, …). These objectives bring new processes to city governance. These new processes require information and knowledge in order for them to be achieved. Part of such information and

Figure 6. City, smart city, IKS, and ICT



knowledge can be supported by ICT. The concept of the Smart City takes account of the potentials of ICT and includes the concept of IKS.

Under the influences of globalization and the impact of ICT, which together radically alter our relationship with space and time, the city increasingly develops its activities in a three-dimensional planetary space:

- A global space covering the series of cities constituting the nation;
- A local space corresponding to the city situated within a given geographical zone; and
- A space in which the city influences and interacts with other cities.

The city confined within its local borders is thus transformed into an open, adaptable, extended city free of borders. Land is the territorial dimension of a city at different levels. These levels may range from the local dimension, to the regional, network, national, and finally, global dimension (Figure 7).

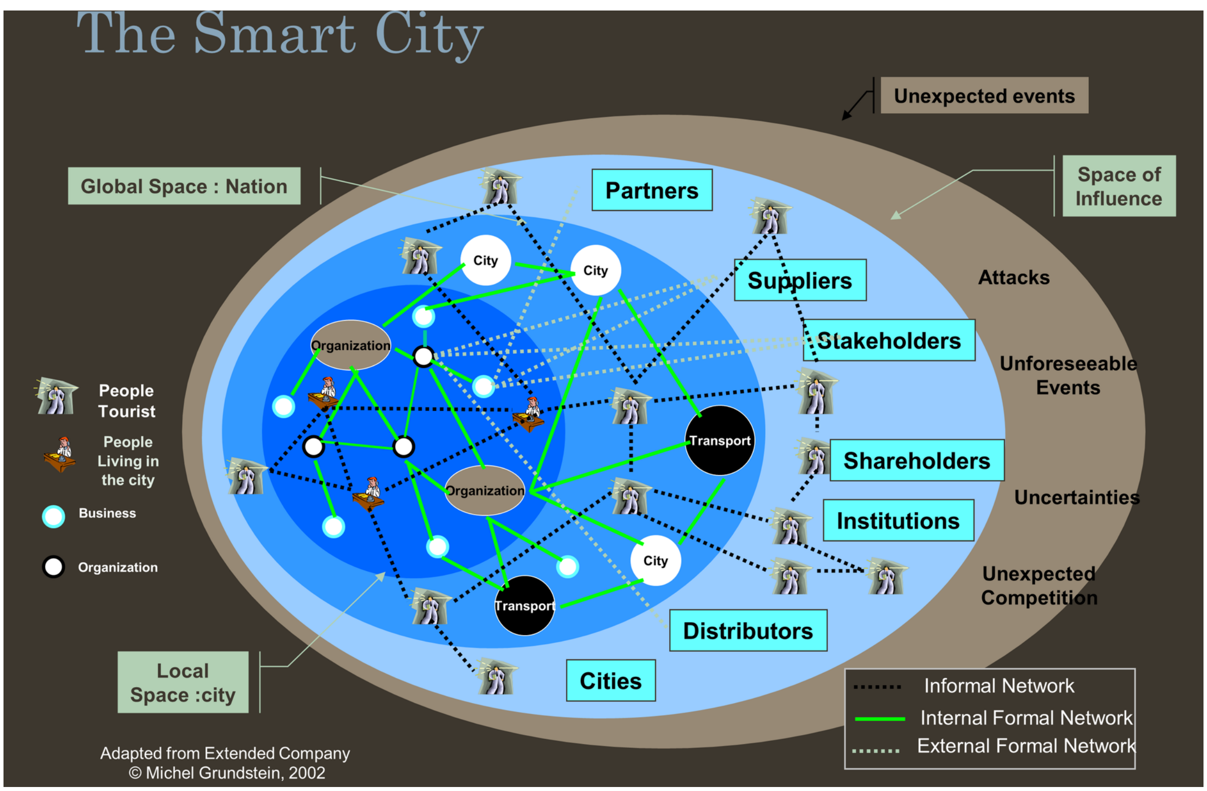
Furthermore, the Smart City is subject to the ascendancy of an unforeseeable environment, which can generate uncertainty and doubt.

The city resolves the fundamental problems of information exchange and knowledge sharing among, on the one hand, its formal entities distributed worldwide, and on the other hand, the city's population (nomadic or sedentary), the bearers of diverse values and cultures.

Two information networks overlap here:

- A formal information network involving internal or external entities, in which data and explicit knowledge circulate. This network operates by means of intranet and extranet technologies.

Figure 7. The smart city



- An informal information network involving the nomadic or sedentary population. This network favours the process of information exchange and of tacit knowledge sharing. It operates through converging Information and Communication Technologies (for example the new IPOD with Web 2.0).

Problems arise when the nomadic population (tourists or students for example) placed in new, unknown or unexpected situations, needs to get "*active information*", that is, the information and knowledge they immediately require to understand a given situation, solve a certain problem, make a decision, and act.

That means that ICT provide the information needed by people who represent the heart of the city. By extension, we believe that ICT bear potentialities, they bring new uses, they lead to new forms of organization and a new vision of the city, what we call a "S*mart City*". ICT thus constitute the very heart of the Smart City.

A city possesses an information system, and since people are hyper-connected and tacit knowledge bearers, the smart city possesses more than just an information system: it boasts an Information and Knowledge System. In fact, the City's Information and Knowledge System (CIKS) principally consists in a set of individuals (people) and Digital Information Systems (DIS). The CIKS is based on a socio-technical setting consisting of individuals (people) that interact among themselves, with machines, and with the very CIKS. It includes:

- Digital Information Systems, which are artificial systems and the artefacts designed by means of ICT;
- An information system constituted by individuals who, in a given context, are processors of data to which they give a sense in the shape of information. This information, depending on the case in question, is passed on, remembered, processed and divulged by said individuals or by the DIS;
- A Knowledge System consisting of tacit knowledge embodied by the individuals, and of explicit knowledge formalized and codified on any kind of support (documents, videos, photos digitalized or otherwise). Under certain conditions, digitalized knowledge can be memorized, processed and divulged through the DIS. In that case, knowledge is merely information.

CONCLUSION

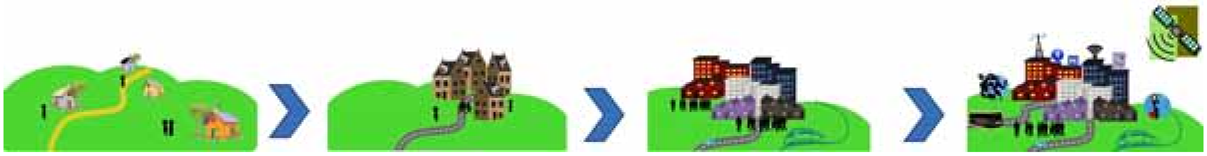
In this chapter, by drawing an analogy with a salad recipe, ingredients and dressing, we propose a form of recipe for the Smart City where the ingredients are the citizens, the environment, Information and Communication Technology (ICT), and the dressing is knowledge.

In our everyday lives, where (i) Information and Knowledge are the heart of the City, (ii) worldwide economies depend increasingly on the use of computers, (iii) ICTs are becoming increasingly important, complex and widely distributed, (iv) the City requires improved productivity, better quality but an increasingly shorter development time, and (v) finally, knowledge can improve the city's decisional processes.

Our vision is a novel one thanks to the concept of the City's Information and Knowledge System (CIKS). The smart city has more than just ICT, and more than just people. It also possesses and deals with knowledge.

Our vision takes people, information and knowledge into account. The advantages of this approach are that knowledge lies at its heart, and that it entails a new vision of the Information and Knowledge System designed to cope with the city's complexity. From our point of view, knowledge is a factor that can contribute towards improving the "*smartness*" of the city.

Figure 8. The Darwinian evolution of cities



The multidisciplinary nature of a smart city program requires that a set of objectives be established. Citizens should be involved in this process, at both the planning and implementing stages of the smart city; communication underlies shared involvement in the establishment of a smart city's goals and in raising awareness of the smart city's role and of its benefits for people (Viitanen & Kingston, 2014).

From our point of view, the smartness of a city can be improved through (i) a more global view of the city (multicriteria, multi-views, context), (ii) a Technological & Human approach, by (iii) taking knowledge into account when considering the smart city concept.

The expression "*Smart City*" covers all managerial actions designed to solve the problems of smartness of the city in general: it is necessary (i) to align management with the city's strategic orientation; (ii) to make people aware; (iii) to educate and motivate all of the city's stakeholders; (iv) to organize and pilot activities and specific processes towards greater mastery of smartness; (v) to encourage the implementation of favourable conditions for cooperative work, and the sharing of knowledge (Bettencourt, 2013; Negre & Rosenthal-Sabroux, 2014).

Figure 8 portrays the evolution of the city over time, starting from a series of scattered houses, followed by the grouping of these houses into cities, which are subsequently industrialized and mechanically connected to other cities (transport), and finally, to the current stage where they are now hyper-connected (with citizens who are connected, who need to access different types of information, while the city itself is connected to the rest of the world) (Kennedy, 2012).

Citizens with an open window looking out on the city and the local surrounds, should be able to receive information and knowledge that is specific to their needs, to have access to data, information and knowledge, and to transmit and share their own tacit knowledge.

In other words, cities must evolve, otherwise they will die!

In conclusion, the question is:

To be smart or not to be smart? The Darwinian evolution of cities…

REFERENCES

Alawadhi, S., & Scholl, H. J. (2013). Aspirations and realizations: The smart city of Seattle. In *Proceedings of Hawaii International Conference on System Sciences* (pp. 1695-1703). doi:10.1109/HICSS.2013.102

Almirall, E., & Wareham, J. (2008). Living labs and open innovation: Roles and applicability. *The Electronic Journal for Virtual Organizations and Networks*, *10*, 21–46.

AMETIC. (2013). *Smart cities*. Barcelona: AMETIC.

Anthopoulos, L., & Vakali, A. (2012). Urban planning and smart cities: Interrelations and reciprocities. In F. Alvarez et al. (Eds.), *Future Internet Assembly 2012. From promises to reality* (pp. 178–189). New York: Springer. doi:10.1007/978-3-642-30241-1_16

Batty, M. (2013). Big data, smart cities and city planning. *Dialogues in Human Geography*, *3*(3), 274–279. doi:10.1177/2043820613513390

Bettencourt, L. (2013). Four simple principles to plan the best city possible. *New Scientist*, *18*, 30–31. doi:10.1016/S0262-4079(13)62903-6

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. doi:10.1080/10630732.2011.601117

Chan, C. (2013). From open data to open innovation strategies: Creating e-services using open government data. In *Proceedings of Hawaii International Conference on System Sciences*. doi:10.1109/HICSS.2013.236

Chesbrough, H. (2003). The era of open innovation. *MIT Sloan Management Review*, *44*(3), 35–41.

Chesbrough, H. (2006). *Open innovation: The new imperative from creating and profiting from technology*. Boston: Harvard Business School Press.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, R., Mellouli, S., Nahon, K., & Scholl, H. J. et al. (2012). Understanding smart cities: An integrative framework. In *Proceedings of Hawaii International Conference on System Sciences* (pp. 2289-2297).

Chua, B., & Brennan, J. (2004). Enhancing collaborative knowledge management systems designs. In *Proceedings European Conference on Knowledge Management* (pp. 171-179).

Dameri, R. P., D'Auria, B., & Ricciardi, F. (2014). Knowledge and intellectual capital in Smart City. In *Proceedings of European Conference on Knowledge Management*.

Dameri, R. P., & Rosenthal-Sabroux, C. (2014). *Smart City – How to Create Public and Economic Value with High Technology in Urban Space*. Berlin, Germany: Springer.

Davenport, T. H., & Prusak, L. (1998). *Working Knowledge: How Organizations Manage What They Know*. Cambridge, MA: Harvard University Press.

Educnet. (2006). *Information system definition*. Retrieved from http://www2.educnet.education.fr/sections/superieur/glossaire/2006

Fernback, J. (2010). Urban planning unplugged: How wireless mobile technology is influencing design elements in seven major US cities. *Communications of the Association for Information Systems*, *27*(November), 651–664.

Ferro, E., Caroleo, B., Leo, M., Osella, M., & Pautasso, E. (2013). The role of ICT in smart cities governance. In *Proceedings of Conference Democracy and Open Government*.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., & Meijers, E. (2007). *Smart Cities - Ranking of European medium-sized cities*. Retrieved from http://www.smart-cities.eu/download/smart_cities_final_report.pdf

Grundstein, M., Rosenthal-Sabroux, C., & Pachulski, A. (2003). Reinforcing decision aid by capitalizing on company's knowledge: Future prospects. *European Journal of Operational Research*, *145*(2), 256–272. doi:10.1016/S0377-2217(02)00533-7

Ishida, T. (2002). Digital City of Kyoto. *Magazine Communications of ACM*, *45*(7), 76–81. doi:10.1145/514236.514238

Kennedy, S. J. (2012). *Transforming Big Data Into Knowledge: Experimental Techniques in Dynamic Visualization.* (Doctoral dissertation). Massachusetts Institute of Technology.

Laudon, K. C., & Laudon, J. P. (2000). *Les systèmes d'information de gestion*. Canada: Pearson Education.

Lima, M. (2011). *Visual Complexity: Mapping Patterns of Information*. New York: Princeton Architectural Press.

Masud, L., Valsecchi, F., Ciuccarelli, P., Ricci, D., & Caviglia, G. (2010). From Data to Knowledge - Visualizations as Transformation Processes within the Data-Information-Knowledge Continuum. In *Proceedings of International Conference Information Visualisation*. doi:10.1109/IV.2010.68

Mc Dermott, R. (1999). Why information technology inspired but cannot deliver knowledge management. *California Management Review*, *41*(3), 103–117. doi:10.2307/41166012

McLuhan, M., & Gordon, W. T. (2011). *Counterblast 1954*. Hamburg, Germany: Gingko Press Inc.

Mitchell, W. J. (1999). *E-topia: « Urban life, Jim (but not as we know it)*. Cambridge, MA: MIT Press.

Nam, T., & Pardo, T. A. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In *Proceedings of International Digital Government Research Conference: Digital Government Innovation in Challenging Times* (pp. 282-291). doi:10.1145/2037556.2037602

Negre, E., & Rosenthal-Sabroux, C. (2014). Recommendations to improve the smartness of a city. In R. P. Dameri & C. Rosenthal-Sabroux (Eds.), *Smart city - How to create public and economic value with high technology in urban space*. Berlin, Germany: Springer. doi:10.1007/978-3-319-06160-3_5

Nelson, R. R., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap Press of Harvard University Press.

Newell, S., Scarbrough, H., Swan, J., & Hislop, D. (2000). Intranets and Knowledge Management: De-centred Technologies and the Limits of Technological Discourse. In C. Prichard, R. Hull, M. Chumer, & H. Willmostt (Eds.), *Managing Knowledge: Critical Investigations of Work and Learning*. UK: Macmillan Business.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-Creating Company*. Oxford, UK: Oxford University Press.

Nurcam, S., & Rolland, C. (2006). *50 ans de Système d'Information: de l'automatisation des activités individuelles à l'amélioration des processus et la creation de valeur ajoutée*. Retrieved from http://www.univ-paris1.fr/fileadmin/diplome_mastersic/chapitreSI_anniversaire.pdf

Polanyi, M. (1958). *Personal Knowledge: Towards a Post Critical Philosophy*. London, UK: Routledge.

Polanyi, M. (1967). *S*ense-giving and sense-reading. *Philosophy: Journal of the Royal Institute of Philosophy*, *42*(162), 301–323. doi:10.1017/S0031819100001509

Porter, M. E. (1979). How Competitive Forces Shape Strategy. *Harvard Business Review*. PMID:18271320

Pyrozhenko, V. (2011). Implementing open government: Exploring the ideological links between open government and the free and open source software movement. In *Proceedings of Annual Public Management Research Conference*.

Reix, R. (2000). *Systèmes d'information et management des organisations*. Paris, France: Librairie Vuibert.

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., & Oliveira, A. (2011). Smart cities and the future Internet: Towards cooperation frameworks for open innovation. In J. Domingue et al. (Eds.), *Future Internet Assembly 2011. Achievements and technological promises* (pp. 431–446). New York: Springer.

Simon, H. A. (1969). *The Sciences of the Artificial*. Cambridge, MA: MIT Press.

Tonchia, S., & Tramontano, A. (2004). *Process Management for the Extended Enterprise*. Berlin: Springer Verlag. doi:10.1007/978-3-642-17051-5

Townsend, A. (2013). *Smart cities: Big data, civic hackers, and the quest for a new utopia*. New York: W. W. Norton & Company, Inc.

Trivellato, B., Cavenago, D., & Beltrami, G. (2013). Is strategic urban planning becoming 'smarter'? Reflections on a selection of European cities". In *Proceedings of EGPA Annual Conference*.

Tsuchiya, S. (1993). Improving knowledge creation ability through organizational learning. In *Proceedings of the International Symposium on the Management of Industrial and Corporate Knowledge* (pp. 87–95).

Viitanen, J., & Kingston, R. (2014). Smart cities and green growth: Outsourcing democratic and environmental resilience to the global technology sector. *Environment & Planning A*, *46*(4), 803–819. doi:10.1068/a46242

Walsham, G. (2001). Knowledge management: The benefits and limitations of computer systems. *European Management Journal*, *19*(5), 599–608. doi:10.1016/S0263-2373(01)00085-8

Wang, H., Song, Y., Hamilton, A., & Curwell, S. (2007). Urban information integration for advanced e-planning in Europe. *Government Information Quarterly*, *24*(4), 736–754. doi:10.1016/j.giq.2007.04.002

Wilson, T. (2002). The nonsense of 'knowledge management'. *Information Research, 8*(1).

KEY TERMS AND DEFINITIONS

ICT: Information and Communication Technology.

Information and Knowledge System (IKS): Principally consists in a set of individuals (people) and Digital Information Systems.

Information System: Is an organized set of resources: material, software, employees, data, procedures, in order to acquire, to process, to store, to disseminate information (data, documents, image, sound, etc.) in organization.

Knowledge Management: Is the management of the activities and the processes that enhance the utilization and the creation of knowledge within an organization, according to two strongly interlinked goals, and their underlying economic and strategic dimensions, organizational dimensions, socio-cultural dimensions, and technological dimensions: (*i*) a patrimony goal, and (*ii*) a sustainable innovation goal."

Sharing Knowledge: Is the tacit knowledge shared among people.

Smart Cities: Cities are smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.

Tacit Knowledge: Is an intangible element.

Chapter 5
Challenges and Opportunities for the Development and Management of Urban Green Areas in Addis Ababa:
The Case of Cooperative Housing Green Areas and Street Trees in Nifas Silk Lafto Sub-City

Gebrye Kefelew
Addis Ababa University, Ethiopia

Tebarek Lika
Addis Ababa University, Ethiopia

ABSTRACT

This chapter examines the challenges of, and opportunities for, the development and management of cooperative housing green areas and street trees. To deal with this issue effectively, the study employed mixed research methods and used questionnaires, in-depth interviews, focus group discussions, observations and desk reviews, for the purposes of data collection. The findings of this study identify a lack of awareness on the part of the public and of government employees, weak institutional capacities, a lack of coordination among stakeholders, and the absence of clear ownership and enforcement mechanisms, as representing the major challenges impacting the development and management of cooperative housing green areas and street trees. Therefore, in order to develop and manage these green areas properly, the study recommends that the good will, the coordination and the efforts of all stakeholders, including communities, government authority, and non-governmental bodies, be enhanced and duly coordinated.

DOI: 10.4018/978-1-4666-8282-5.ch005

INTRODUCTION

The concept of the smart city is not a static one: there is no absolute definition of the smart city, no end point, but rather a process, or series of steps, by which cities become more "livable" and resilient, and thus able to respond more quickly to new challenges. The Office for the Revision of the Addis Ababa Master Plan has also explained that a smart city includes not only smart technologies, but also smart residents, smart mobility, a smart economy, smart housing, smart governance, and smart urban green area development and management. Thus, the development and management of urban green areas such as cooperative housing green areas and street trees, which are the focus of this chapter, are part of the definition of the Smart City in Addis Ababa. This is due to the fact that the development of multi-functional cooperative housing green areas and street trees contributes towards the aims of the smart city in terms of the improvement in the quality of life and environment for the city's population (Alamrew, 2002). The preservation of cooperative housing green areas and street trees in and around the city, also provides psychological satisfaction for the residents. An interesting insight into the purpose of urban green areas and their contribution to smart city development, is provided by Wondimu (2006). He argues that a city or town without sufficient green space can be qualified as an organism with no respiratory system.

As the city of Addis Ababa is now in the process of rapid economic transformation and urbanization, there is growing concern about the fate of green areas. The capital was once called the "forest city". In fact, at the beginning of the 20th century, some 10 million trees were imported from Australia and planted all over Addis Ababa (Berlan, 1963 cited in Wondimu, 2006). Since the nationalization of land in 1975, the green areas in the capital have been subjected to excessive exploitation and severe degradation due to the lack of careful management of green areas and inadequate greening activities (Horst, 2006). Recently, the city administration has been also unable to keep pace with the expectation emanating from the services and facilities of urban green areas and the city's international notion. Moreover, the smart development and management of urban green areas in Addis Ababa barely meets the standards set by other rival African cities, or even the standards set out in the master plan of the city itself (ORAAMP[1], 1996).

The smart development of cooperative housing green areas and street trees is usually planned and indicated in the settlement plan and road design of Addis Ababa. However, these green areas are not operating properly, or are not used appropriately by the residents of Addis Ababa. There are many problems related to these urban green areas, one of which is the level of cleanness. It is true that cleanness is one of the operational attributes for the good quality of urban green spaces, as this creates comfort and convenience for its users. Addis Ababa, however, is not lucky enough to have clean cooperative housing green areas and street trees. Indeed, in some cases these urban spaces are places where homeless people live, dump their garbage and use as toilets. Furthermore, the absence of the effective, timely cleaning and maintenance of these spaces further aggravates the problems.

Cooperative housing green areas also have problems concerning their current functionality and operation. In principle, they should serve all members of the housing cooperative; and they have to be accessible to such members. However, some of these areas are closed, or are simply vacant lots which do not offer any kind of public service. This situation also negatively impacts the environment, the appearance and the economic development of the city.

Generally, these green areas suffer in terms of their appearance, maintenance and cleaning. Moreover, there are also problems related to the extent of the availability and practicality of these urban spaces. However, Addis Ababa is going through a process of transition. Planning for future development and the implementation of management strategies are therefore essential for such urban spaces. However, very little systematic research has been carried out into cooperative housing green areas and street trees in Addis Ababa City.

All the aforementioned problems are also true in the subject area of this study, Nifas Silk Lafto sub-city (NSLSC[2] BPCDM[3] office report, 2011). They are once again the result of the approach taken to the planning and development of these spaces, or of their management, or perhaps the combination of all such factors. Therefore, the challenges faced by cooperative housing green areas and street trees need to be analyzed in terms of planning for development and introducing better management mechanisms to expand the available services by taking advantage of existing opportunities in Nifas Silk Lafto sub-city.

This chapter aims to answer the following questions:

1. What problems are involved in the development and management of cooperative housing green areas and street trees?
2. What are the current local strategic practices for developing and managing cooperative housing green areas and street trees?
3. In what ways are the stakeholders involved in the planning, development and management of cooperative housing green areas and street trees?
4. What opportunities exist for the development and management of cooperative housing green areas and street trees?

THEORETICAL INSIGHTS

The Development and Management of Urban Green Areas as a Contribution towards the Development of Smart Cities

The concept of smart cities is difficult to define. The idea underlying the term "Smart City" is that by using innovation and technology, resources can be used much more efficiently. The term has a technological background and origins. Recently the concept of smart cities has gone beyond mere technological advancement, and many actors from different disciplines have tried to use various characteristics to define the concept of Smart City. For instance, Giffinger (2007) used six smart categories – People, Mobility, Living, Government, Economy and Environment – for an international ranking of Smart Cities. This typology has also been used by the European Commission (2014).

As we have inferred from the aforementioned concept of the Smart City, aspects of the urban environment such as green areas are considered to constitute smart city categories. The quality of life is also a major objective for most Smart City strategies. Well-functioning, attractive public spaces, together with an attractive environment, can act as symbols of a city and of living together, and may create a sense of ownership of the city among its population (European Commission, 2014). The same author also explained that public open spaces such as cooperative housing green areas and street trees are important factors when defining a city's "smartness".

Urban Green Area Development and Management

Recent studies have shown that planning the development and management of urban green areas requires the integration of the views of both planner and user. For instance, a study in Madina showed that the majority of users (80%) and (71%) want grass / turf and evergreen plants in their green spaces respectively (Irum et al., 2002). This indicates that during the planning, development and management process, users' views should be taken into account. If urban green space development strategies fail to include stakeholders' participation, this implies that social and environmental functions are being neglected (Balram & Dragicevic, 2005).

A study in Ankara, Turkey, shows that green space users' preferences include sitting on benches, walking and running facilities, a pleasant landscape, visual elements, nearness to water and a peaceful atmosphere (Oguz, 2000). In the pursuit of the development of quality green spaces, the standards should be set locally to accommodate requested activities and future changes. Public participation in the urban green area development and management process is very important if their values and ways of life are to be incorporated into the process[4].

Experiences involving the development of urban green areas also demonstrate that an effective way of managing urban green areas should be formulated according to an integrated approach and through subject-specific (thematic) strategies. An integrated approach entails the active involvement of the community, together with cooperative, enabling partnerships between local authorities, local businesses and voluntary groups (Bartone et al., 1994). The management of urban green areas within the overall functional area of a political authority and/or built-up city is also a thematic strategy (European Commission, 2007). Moreover, this approach is based on cross-departmental/sectoral cooperation, engagement with all relevant stakeholders, and the integration of local, regional and national policies[5].

Baycan-Levent and Nijkamp (2004) stated that urban green area development and management requires the active involvement of public, private and non-governmental actors at individual, community, city and national levels. Urban green area development and management should therefore involve those whose interests are affected both by green problems and by management strategies and action plans; that is, those who exercise control over the instruments used for implementing green management strategies, and those who possess the relevant information on a wide range of green issues.

Practical Experience of the Planning of Urban Green Areas in Ethiopia

The consideration of urban green areas in country's urban planning ventures and other social and economic development undertakings, has paramount importance for sustainable development. In this regard, the urban planning process in Ethiopia has been incorporating the issue of urban green areas in the overall planning exercise since 1886 (Fetsum, 2003). Fetsum (2003) also pointed out that this is reflected in the incorporation of green areas and parks in urban plans, the consideration of the compatibility of various land uses, the incorporation of generalized environmental objectives, and the identification of hazardous areas. In spite of such efforts, the facilities in urban green areas, even in the capital of Ethiopia, hardly meet the standards set by other rival African cities (ORAAMP, 1996). In order to address these problems, the government of Ethiopia has issued various supporting guidelines, policies and proclamation. These include the Ethiopian Constitution of 1995 (FDRE, 1995), the Ethiopian Environmental Policy of 1997 (FDRE, 1997), the Ethiopian Urban Development Policy of 2006 (Ministry of Federal Affairs, 2006), and its Urban Planning Proclamation no. 574/2008c (FDRE, 2008)

The Ethiopian Constitution establishes a series of general principles requiring that all people be given the opportunity to live in a clean, healthy environment. The concept of sustainable development and environmental rights are also enshrined in Article 43, 44 and 92 of the Constitution of the Federal Democratic Republic of Ethiopia (FDRE). While different action plans and proclamations are designed in line with the Constitution, federal, regional and local governments can design and implement supporting proclamations and various action plans designed to develop and manage cooperative housing green areas and street trees.

Moreover, the Environmental Policy of Ethiopia has recognized the importance of planning and creating green spaces within urban areas. This provision also creates opportunities for various stakeholders to develop and manage cooperative housing green areas and street trees as elements of urban green areas. Moreover, the Urban Development Policy of Ethiopia has recognized cities as entities that strive to work towards minimizing any serious risks to the urban environment. The policy document also pledged that the city government would work towards:

The development and protection of urban green areas, designing and developing environmental friendly development projects, planting and protecting institutional parks, residential green areas, street tree[s], and informal green areas, ensuring that an exemplary and leading role is played by the government and [ensuring] the participation of the private sector in environmental protection, selecting and adapting best practices, experiences and technologies suitable for urban environmental protection (Ministry of Federal Affairs, 2006).

Thus, urban development policy has rendered city governments responsible for the development and management of residential green areas such as cooperative housing green areas and street trees, with the joint involvement of other stakeholders. Furthermore, Urban Planning Proclamation no. 574/2008c has made chartered cities and urban administrations one of the institutional areas for environmental protection in Ethiopia. It has also prohibited any kind of urban development project that fails to take account of the detrimental impact on the urban environment in general, and on urban green areas in particular. All these are very important advances in the urban green area development and management in Ethiopia.

Experiences in Addis Ababa

The idea of a radial ring road surrounded by green belts was introduced by the second master plan for Addis Ababa. The plan was prepared by the planner of Greater London, Patrick Abercrombie (ORAAMP, 1996), upon request from Emperor Haile Selassie I. However, cooperative housing is a recent phenomena which only saw the light of day in the late 1970s as a result of the 1975 revolution.

The development and management of cooperative housing green areas and street trees are fundamentally inadequate. In order to rectify this situation, CGAA (2011) has introduced a number of undertakings, plans and actions comprising, among others, the City Development Plan of Addis Ababa, the Clean and Green Addis Ababa Development Plan, and the manual of the BPCDM Agency of the City Government of Addis Ababa. The Development Plan of Addis Ababa, which is currently under review, called for tree planting along the city's ring roads and existing streets, and imposed one-plot-one-tree requirements. The Clean and Green Addis Ababa Development Plan (CGAADP) was prepared in 2004 by the City Government of Addis Ababa in partnership with the Clean and Green Addis Ababa Society. The plan covered the period 2004-2025, and contained a number of interesting measures and ambitious programs regarding the greening of roadsides, median strips and open spaces. Moreover, the manual of the BPCDM Agency of Addis Ababa's city Government indicated a series of different institutions through which local residents could be involved in the development and management of cooperative housing green areas and street trees. The institutions and their corresponding responsibilities, are as follows:

- Urban Plan Preparation and Information Office: responsible for preparing plans for cooperative housing green areas' development.
- Land Development and Ownership Administration Office: responsible for providing land records and other legal documents for cooperative housing green areas.
- Design and Construction Management Office: responsible for providing design standards for the development of cooperative housing green areas and street trees.
- Environmental Protection Authority Office: responsible for implementing Ethiopia's environmental policy with regard to the development and management of cooperative housing green areas and street trees; and for providing tree species planted on cooperative housing green areas and at road junctions.
- Addis Ababa Road Authority: responsible to provide evidences about the location of utilities which are found at the right-ways of the road.
- Water Development Office of the city: responsible for providing water services for the development of cooperative housing green areas and street trees.
- Justice Office: responsible for interpreting different environmental protection proclamations for the management of cooperative housing green areas and street trees.

RESULTS AND DISCUSSIONS

Challenges for the Development and Management of Cooperative Housing Green Areas and Street Trees

As the experience of Addis Ababa shows, the provision of land for citizens to construct houses through cooperatives also includes land designated as green space. In this regard, all 130 respondents (100%) replied that they had received land for the purpose of creating green areas, while the government provided them with land to construct houses through local cooperatives. In principle, these areas are allotted as breathing, recreational and social spaces for local neighborhoods. However, an examination of the archives in the study areas revealed that the development and management of cooperative housing green areas has deteriorated over the course of time.

Survey respondents were also asked to identify the challenges which hinder the development and management of cooperative housing green areas in their neighborhoods. 40% of respondents (52) said that the development and management of cooperative housing green areas is hindered due to public and government employees' lack of awareness of the causes and consequences of cooperative housing green areas' degradation, and of the benefits of the development and management of these areas. These may aggravate the loss, degradation and occupation of cooperative housing green areas by different sections of the community. The second largest group, 35% (45), said that the lack of active participation among stakeholders weakens the joint efforts of various actors to influence the process of development and management of cooperative housing green areas. A quarter of respondents (33) also mentioned that the hindered development and management of cooperative housing green areas was due to the lack of clear ownership and enforcement mechanisms. Such situations leave residents with limited opportunities to develop and maintain their cooperative housing green areas.

Key informants from different government offices[6] directly or indirectly involved in the issue at hand, also confirmed the above-mentioned factors. Moreover, they described more specific challenges affecting the development and management of cooperative housing green areas. In their view, these challenges include:

- The lack of commitment, among different sections of the public, to complying with various drafted and enacted environmental proclamations, hinders the applicability of various proclamations to the management and maintenance of cooperative housing green areas; the lack of a clear, up-to-date database of cooperative housing green areas. For instance, the GIS map of the sub-city shows cooperative housing green areas as empty spaces, leading government to use the areas for other purposes. For this reason, cooperative housing green areas such as the green area of the Tewahido cooperative housing, are being used for waste dumping purposes; and
- The lack of cross-sectoral cooperation and the rival agendas of the offices in question, has contributed towards hindering the development and management of cooperative housing green areas. "Cooperative housing's green areas development and management have not been given sufficient attention even in the preparation of local development plans" due to the lack of coordination among the urban planners, the information office and the BPCDM office of the sub-city. However, Bartone et al. (1994) argue that the effective and sustainable development and management of urban green areas will only be achieved when the development and management of urban green areas are given sufficient weight when preparing local development plans. Thus, what is actually being done in the study area is different from this standpoint.

Politicians working on land-lease related issues sometimes allocate cooperative housing green areas for other uses in order to save land for different forms of development. Similarly, the focus group participants have pointed to various challenges that affect the development and management of cooperative housing green areas. In their view, these challenges include:

- The lack of proper plan implementation, which offers opportunities for the conversion of cooperative housing green areas for other purposes such as housing, waste dumping, stores for the residents' *Iddir*[7], etc.;
- The lack of education and research regarding cooperative housing green areas, in order to plan appropriate action for the future greening of the areas;
- The disintegration of various cooperatives, thus limiting members' ability to develop and manage their common spaces in a coordinated, integrated manner;
- The lack of proper protection, follow-up, monitoring and evaluation of activities pertaining to the use and conservation of the areas by the government organs in question. This situation has created an environment conducive to incursion into cooperative housing green areas so as to use these areas for other purposes, such as official and unofficial housing construction, parking, for the residents' *Iddir*, and so on;
- Insufficient media coverage of cooperative housing green areas has contributed to the limited public awareness of the importance of the areas in question;
- The lack of any real links between government agencies and the members of the cooperatives, thus hindering the joint efforts needed for the development and management of cooperative housing green areas;
- The various different government offices responsible for the development and management of cooperative housing green areas are not duly coordinated, and are accountable to other, different offices. This

leads to competition between such offices, rather than cooperation, as a result of a conflict of interests; and

- The lack of accountability among the members of the cooperatives with regard to their green areas, which manifests itself in their lack of concern regarding the degradation of their cooperative housing green areas.

Local Strategies and Practices for the Development and Management of Cooperative Housing Green Areas

In the manual of the CGAA's BPCDM agency, the overall strategies for green area development and management are set out in a manner revealing a clear hierarchy of politicians, municipal administrations and other city stakeholders at all levels. The manual also mentions the fact that the strategies for the development and management of cooperative housing green areas are run by the sub-city and woredas' BPCDM offices, in conjunction with other government institutions[8] and with the members of the housing cooperatives. However, the various institutions responsible for designing local strategies do not work in conjunction with the BPCDM office. The reasons for this are as follows:

- Most of these institutions often focus on contingent, highly visible problems such as poverty, unemployment, the lack of housing, etc.;
- Some of these institutions have overlooked the environmental benefits and services associated with cooperative housing green areas, thus making them less inclined to design and implement specific strategies for the development and management of such spaces; and
- The above-mentioned institutions are more likely to compete with each other than to cooperate, which in turn reduces their commitment to designing and implementing the various strategies jointly.

Cooperative housing green areas are developed and managed by the members and committees of the housing cooperatives or *Iddirs* in the study area. However, this strategy is ineffective since most cooperative housing green areas are not clearly registered as the property of the cooperatives.

As far as concerns local strategic practices, a conference was held in 2010 in conjunction with the members of the Medirok and American housing cooperatives, on the topic of the importance of green areas to cooperative housing. The following forms of support were also provided to the members of Medirok and American housing cooperatives by the Woreda (District) 1 BPCDM office:

- Programs to raise awareness of the benefits of cooperative housing green areas;
- Networks were created with, and various supporting letters written to, other infrastructural sector offices such as the water and electricity boards, in order to readily obtain water and electricity services for their green areas;
- Legal letters were sent and land administration authority requested, in order to get cooperative housing green areas recognized as the property of the members of the cooperatives. Recognition was given as a result of such;
- Guiding and monitoring the activities carried out within the green areas of the housing cooperatives, in order to facilitate the management of green areas for environmental and recreational purposes.

Following the conference and the abovementioned forms of support, the committees of the Medirok and American housing cooperatives acted as lobbies in an attempt to persuade government officials of the importance of cooperative housing green areas for urban life. Therefore, providing different awareness-raising programs to the members of the cooperative, with regard to cooperative housing green areas, and ensuring the tenure security of the green areas in question, are vitally important if appropriate strategies are to be designed and implemented. Current research supports this argument, since the members of the two housing cooperatives in question have started to maintain their green areas as shown below.

On the other hand, not all members of the various housing cooperatives were willing to contribute money; and could not take initiatives to design strategies for the development and management of their cooperatives housing green areas due to:

- The residents' limited awareness of the benefits of the development and management of cooperative green areas;
- The lack of confidence among the members of the cooperatives with regard to the tenure system of cooperative housing green areas. This situation lowered the willingness of cooperative members to participate in the design and implementation of various strategies for the development and management of their green areas.

Moreover, field observations show that most cooperative housing green areas have not been properly developed and managed; no greening or conservation has been undertaken, and they have become dumping areas rather than recreational spaces. This situation clearly indicates that local strategies for the development and management of cooperative housing green areas are incapable of addressing the problems relating to the development and management of the areas.

The Stakeholders' Involvement in Planning, Developing, and Managing Cooperative Housing Green Areas

Beer and Jorgensen (2003), in their study of Scandinavian cities, reported that residents' involvement in the development and management of cooperative housing green areas processes had increased the quality and the facilities of the green spaces in question. The current study, on the contrary, reveals that 69% (90) of survey respondents did not participate in the planning, development or management of cooperative housing green areas, with only 31% (40) of respondents replying that they were involved in those processes. Community involvement in planning green areas takes a variety of different forms, such as providing funding, attending awareness-raising programs, offering technical assistance, and also submitting ideas. However, survey results show that contributing money was preponderant, followed by attending the occasional awareness-raising program. Of this group of respondents, none of them had offered technical assistance, or submitted ideas for the planning and assessing of the community's needs. Of those respondents who did not participate in any way, almost 71% (64) said a lack of opportunities, unclear property rights regarding their green areas, and a lack of information, prevented them from participating in the planning process. Some 29% (26) also responded that their participation had been hindered due to the lack of motivation in the communities in question.

Of the 31% (40) of respondents who declared that they had participated in the development and management of cooperative housing green areas, 58.3% (23) replied that they had contributed money to, 18% (7) said that they had attended the occasional awareness-raising program organized by the government, 13.7% (6) responded they had participated in the planting of trees and the sowing of grass in their green areas, while 10% (4) replied that they had participated in community clean-up campaigns to rid the green areas of various types of litter and waste.

The survey results also indicate that the majority of the respondents had participated in the development and management of cooperative housing green areas through the contribution of money. Their participation in various awareness-raising programmes, and in planting trees, sowing grass and cleaning litter from their green areas, was relatively limited.

Key informants from different government offices (institutions) directly or indirectly involved in the issue, have confirmed the aforementioned nature of local residents' involvement in the planning, development, and management of cooperative housing green areas. As far as planning is concerned, the manual of the CGAA's BPCDM office reveals that there is no professional planner assigned to the planning of the green areas' development. Responsibility for such planning activity has been given to the sub-city's Urban Plan Preparation and Information Office. According to the aforesaid manual, the BPCDM office is responsible for conducting need assessments in relation to green areas, in line with the development of the settlements in question. However, this arrangement is "a fact on file", as no expert from the BPCDM office has ever been actually involved in the preparation of local development plans. This is also an indication that what is actually being done does not correspond to what is set out in the manual or the guidelines. This is due to a lack of interest among the various professionals concerned in working in a coordinated manner.

Notwithstanding the foregoing, the three Woredas' BPCDM core process officers stated that their offices had done their share in providing a number of development and management concessions, together with continuous follow-ups and support for the members of the cooperatives. The officers also mentioned that the members of the cooperatives are responsible for any capital investment costs for the development and management of their green areas. Furthermore, the performance standards to be met by the green areas are to be established by their offices, according to the Officers.

Observations regarding those green areas, the management of which has been taken over by the members of the cooperatives, reveals that there has been a certain improvement in the aforesaid green areas. The registered improvements in the green areas of the Abenezer housing cooperative can be attributed to the management system employed. This finding also tallies with Beer and Jorgensen's work which indicated that residents' involvement in the management of cooperative housing green areas improved the quality of the areas in Scandinavian cities. On the contrary, findings regarding green areas not run by the members of the cooperatives in question show that the areas are being used for waste dumping purposes.

Different stakeholder institutions explained that they did not actively participate in the planning, development or management of cooperative housing green areas. Moreover, officers from the NSLSC code enforcement office explained that the office was unable to resolve the problems of the illegal misuse of, and encroachment upon, cooperative housing green areas, due to a lack of clear laws and regulations governing cooperative housing green areas. In this regard, one code enforcement officer from Woreda 3 recounted his experience as follows:

The invasion of the 'Dirbiabir' cooperative housing green area by the official construction boom was brought to the attention of my office. Subsequently another code enforcement officer and me, we went to the area and told the owner of the construction site that the area was a green area of the Dirbiabir housing cooperative. However, the owner of the construction site produced his legal construction permission and property deed that had been issued by the sub-city's land develop-

ment and ownership administration office. We then went to our office and asked the Woreda's urban planning officer to check its legality. The Officer said that the area in question was the green area of the cooperative, according to the map of the cooperative. Therefore, due to the absence of any clear enforcement mechanism and of coordination among stakeholders, we cannot implement any preventive measures or redress the problem.

Opportunities for the Development and Management of Cooperative Housing Green Areas

Recently, the lack of green areas has become a concern of the entire community throughout Addis Ababa. This concern has generated some interesting opportunities (initiatives, plans, and actions) at different administrative levels. Such opportunities include the formulation of general policy frameworks such as the Environmental Policy, the Urban Development Policy, the Urban Planning Proclamation no. 574/2008c, and the Constitution of Ethiopia containing a general framework for the development and management of urban green areas. Moreover, the City Development Plan of Addis Ababa and the Clean and Green Addis Ababa Development Plan of 2004 contained a general framework for the development and management of urban green areas. Different areas covered by this study reveal the existence of certain opportunities to help develop and manage cooperative housing green areas. In fact, certain actions and the involvement of housing cooperative members in the development and preservation of their green areas are encouraging.

Survey respondents were asked to describe what opportunities there were to help develop and manage cooperative housing green areas in their neighborhoods. Of the 130 respondents, the majority 61% (79) replied that the existence of their green areas as vacant land represented an opportunity to develop such areas in the future. Some 30.7% (40) stated that the existence of a strong community based organization like *Iddir* was a good opportunity for joint undertakings aimed at the development and management of their cooperative housing green areas. Only 8.3% (11) thought that clean, green initiatives undertaken by the community and other stakeholders represented a good chance to develop and manage their cooperative housing green areas. On the other hand, the focus group participants pointed out that these opportunities can only be grasped if they are accompanied by awareness-raising programs, continuous follow-up and monitoring services.

Key informants from different government offices have also confirmed the benefits of the aforementioned opportunities for the development and management of cooperative housing green areas. They have also indicated the following opportunities:

- The establishment of BPCDM offices at different levels of the city;
- The manual of local development plan preparation explicitly cites urban green areas as essential elements of urban services;
- The existence of undeveloped and semi-developed green areas in the hands of cooperative members, the introduction of GIS and remote sensing to the office as another opportunity for managing land designed for different purposes, such as land reserved for green areas; and
- The office's recently formulated enforcement manual which shows its intra- and inter-sectoral linkages with other offices.

Challenges for the Growth and Management of Street Trees

Street junctions and median strips comprise the most important opportunities for planting trees within the city. These trees also provide multiple benefits for business communities, residents and tourists. In order to obtain these advantages, different types of tree species have been planted both at the sides and in the medians strips of the roads comprised within the study areas, as shown in Table 1.

However, the aforementioned data revealed that 55% (1019) of the planted trees had died; only 45% (821) had survived. One can also see that the surviving street trees are not getting proper maintenance and protection in the study areas. Field observations of the surviving street trees have revealed that their growth and management are poor.

In an attempt to get residents' views regarding the growth and management of street trees, 130 respondents who were living adjacent to street trees were asked to express their opinions. 84.6% (110) of respondents said that the street trees were not growing properly or being duly maintained. Only 15.4% (20) of respondents reported that the street trees were being managed fairly well. From this, one can see that the street trees in question are not being properly cared for.

Survey respondents were also asked to identify the problems associated with the growth and management of street trees in their neighborhoods. 47% (61) of respondents stated that the community's wrong perception of the purpose of street trees hindered their development and management. Consequently, communities failed to act in order to care for and conserve these trees. The second largest group – 28% (36) – said that stakeholders' lack of participation had weakened the joint efforts of various actors needed for the growth and management of street trees. 25% (33) of them also mentioned that the growth and management of street trees had been hindered by street vending. This unofficial form of trading had a negative impact on the growth and management of street trees. Key informants have confirmed the above-mentioned factors. In addition, they have also mentioned specific problems affecting the growth and management of street trees. For example, insufficient institutional capacities characterized by the absence of continuous follow-up, the lack of trained staff capable of creating more effective, integrated partnerships with business communities, and the lack of financial resources, were perceived as critical factors for the BPCDM office's failure to fulfill their responsibilities effectively. Various different unofficial activities relating to the construction industry, such as the dumping of construction materials near to the street trees, also affected the latter's development and management. Furthermore, the poor selection of tree species designed to combat carbon dioxide emissions, and the installation of urban infrastructural facilities such as fiber-optic lines, all negatively affect the growth of street trees.

The focus group discussants, key informants and survey respondents together identified the following problems affecting the growth and management of street trees:

- The lack of an integrated data base of street trees, which affects the efforts of various stakeholders to design and execute appropriate course of action for the growth and management of street trees;

Table 1. Planted street trees and their status within the study areas

No.	Plant Types	Places Where Street Trees Are Planted	Number of Planted Trees	Surviving Trees (%)	Protected Trees (%)
1	Gravilia	Around Jemo	400	42	30
2	Jacaranda	Around Micheal Square	400	25	20
3	Zenbabaselen	Around Mekanisa and Jermen square	640	43	26
4	Zenbabapicok	Around Bisrate Gebreal and Sar Bet	400	47	35

(Source: NSLSC BPCDM office street trees inventory report, 2011)

- The communities do not feel that the trees belong to them. This feeling discourages the communities from participating in the development and management processes;
- The absence of integrated systems for the management of the street trees in different parts of the neighborhood;
- The lack of action plans for volunteers, resulting in lower volunteer participation in the growth and management of street trees;
- The absence of clear norms and standards governing the minimum distance to be observed between main roads and footpaths, and the places where the street trees are to be planted. Consequently, street trees are planted on footpaths and pedestrian ways, which leads to their deterioration as a result of the transit of pedestrians;
- Traffic accidents have also contributed towards the deterioration of street trees.

Local Strategic Practices Aimed at the Growth and Management of Street Trees

Local authorities are expected to take the lead in forming partnership with other local public sector agencies to develop wider community strategies for improving the economic, social and environmental well-being of their local areas. This would help them contribute towards the achievement of sustainable development (European Commission, 2007, p. 7). These strategies are often prepared and implemented by local authorities through local strategic partnerships bringing together different sections of the community, such as businesses and others. Therefore, it is a good idea to assess the types of local strategic practice being followed to develop and manage street trees in the study areas.

The Nifas Silk Lafto sub-city BPCDM officer mentioned various factors, such as the need for continuous maintenance of street trees under a sustainable system, the increasing damage to street trees, and the public's misperception of the value (benefits) of street trees within the sub-city, as having prompted the office to devise a long-term strategy for street tree development and management. According to her, the strategy has been adopted by the Woredas' BPCDM core process offices.

The three Woredas' street tree development and management policy document states that street trees are grown and managed by government officials, residents, business communities and voluntary groups. As for strategies, the development and management of street trees will be assigned to the abovementioned stakeholders in the form of adoption modalities by Woredas BPCDM core process officers. The strategies also set out a long-term vision for the development and management of street trees in an integrated framework, which is to be complied with and followed-up continuously. To demonstrate the values of street trees to partners, the strategy also provides evidence of the contribution made by street trees to the general appearance of the city and to urban life in particular.

Accordingly, the core processes resulted in a number of street tree development and management agreements between local government officials, residents, business communities and voluntary groups. However, an evaluation of the implemented strategies indicated in Woredas' street tree assessment report, shows that only 35% of the drafted strategies were actually implemented. According to the informants and focus group participants, the lack of implementation was attributed to insufficient awareness of the benefits of the strategies on the part of those officers concerned, together with the non-provision of incentives to volunteers. However, the study's findings also revealed that there are significant differences between those trees given to business communities, and those that are not.

Stakeholders' Involvement in Planning, Growing, and Managing Street Trees

According to the literature, stakeholders' participation involves the combined efforts of a great many institutions, organizations and individuals, aimed at the successful planning, development and management of urban green areas. It also indicates that cooperation among stakeholders is the way to achieve a greater synergy involving more than just the exchange of information or even collective decision making: partnerships, mutual trust and understanding are also required.

Contrary to the above arguments, the results of our questionnaires indicate that 65% (85) of respondents do not participate in the planning, growth or management of street trees. Almost 68% (58) of such respondents said that the lack of opportunities to do so prevented them from participating. Some 32% (27) responded that their participation was hindered by the lack of information. Moreover, almost 80% (68) of those respondents who do not participate in the street tree planning, development and management processes also said that government was doing this work. The remaining 12.5% (11) and 7.5% (6) of respondents, respectively, said that business communities or NGOs were participating in the planning, growth and management of street trees.

Stakeholders' involvement in growing and managing street trees takes different forms, such as the provision of suitable soil and water, planting trees, preparing holes for the planting of trees, and so on. Of the 35% (45) of survey respondents who participated in the growing of street trees in their neighborhoods, 33% (24) replied that they did so by providing suitable soil; 24.5% (11) responded that they contributed by planting trees along the ring roads; and 22.2% (10) answered that they dug holes to plant the trees. Others were involved by both planting trees along the ring roads and by digging holes for the trees. On the other hand, 78.3% (35) of said participants responded that their involvement consisted in watering the trees; 20% (9) said they were involved in the fencing off and protection of the street trees; and 1.7% (1) responded that they took part in raising the community's awareness of the fact that the trees belonged to them.

According to the BPCDM agency's manual, BPCDM offices at various different administrative levels are in charge of the planning, growth and management of street trees with the active involvement of different stakeholders such as local residents, business communities and NGOs. In order to know to what extent the government institutions in question fulfilled their responsibilities, officials from said government institutions were duly interviewed. The information obtained from the key informants is reviewed below.

According to the BPCDM agency manual, the street tree plan needs to be discussed in detail with experts from the Addis Ababa Road Authority. Recently, a number of discussions have been held with the Addis Ababa Road Authority regarding street trees planning. The road property protection and management team leader at AARA stated this point. A team leader also stated that "CGAA's BPCDM agency and its office at sub-city level, together with AARA, discuss and evaluate their plans and strategies twice a year".

BPCDM offices at the sub-city and Woredas level have taken various forms of action for the purposes of the decoration, greening and protection of streets in the sub-city, by planting and maintaining street trees. The BPCDM agency's manual states that the Clean and Green Addis Ababa Development Plan (CGADP) is being implemented by BPCDM office at different levels of the sub-city with the involvement of other stakeholders such as business communities and NGOs. Similarly, the three Woredas' BPCDM core process officers said that various activities are being carried out by their offices and by different business communities, but the results have been insignificant. This is because various initiatives and actions are not implemented in a sustainable manner and with massive community involvement, due to:

- The lack of trained personnel capable of growing and managing street trees systematically;
- The fact that staff turnover has led to a lack of any integrated database and information about the status of the street trees;
- The unwillingness of professionals to provide home-to-home awareness raising programs concerning street trees for the communities; and
- The fact that large business communities are no longer interested in participating in planting trees along roads and at junctions owing to conflicts of interests.

As far as the development and management of street trees are concerned, field observations in different parts of the study areas revealed that the situation is very discouraging. However, those street trees that have been planted nearest to voluntary groups are receiving proper care.

Opportunities for the Growth and Management of Street Trees

All the different policies, plans and proclamations drawn up, such as the Constitution of Ethiopia, the Environmental Policy, the Urban Development Policy, and Urban Planning Proclamation no.574/2008c, contain general provisions for the development and management of urban green areas. More specifically, the City Development Plan of Addis Ababa, and the Clean and Green Addis Ababa Development Plan of 2004, see the greening of roadsides and median strips as one way of developing and nurturing green areas in the city of Addis Ababa. All these provisions should create conditions conducive to the specific implementation of courses of actions for the growth and management of street trees.

Moreover, survey respondents were asked to describe the opportunities for the creation of an environment conducive to the growth and management of street trees in their neighborhoods. Accordingly, about 52.3% (68) of respondents said that government involvement in street tree development and management represented a good opportunity. Some 30.8% (40) said that clean, green initiatives by the community and other stakeholders such as NGOs represented a good chance to develop and manage these trees. The remaining 16.9% (22) suggested that the business community's involvement in the growth and management of street trees should be perceived as a good opportunity for the creation of such an environment. Key informants from different government offices also identified similar opportunities. They also pointed to the establishment of BPCDM offices at different municipal levels; to the BPCDM agency's recently drafted enforcement manual that reveals its intra and inter-sector links with other offices; and to recent government partnerships with private concerns such as voluntary groups, business communities and social groups, involving their participation in such projects, all of which are perceived as good opportunities for the development and preservation of street trees.

CONCLUSION

A lack of awareness on the part of the public and of government employees, together with limited institutional capacities, a lack of coordination among stakeholders, the absence of an up-to date data base, and the lack of clear ownership and enforcement mechanisms, have emerged as serious problems affecting the development and management of cooperative housing green areas. Similarly, the public's misperception of the benefits of street trees, the non-participation of stakeholders in the development and management of green areas and street trees, and the absence of an integrated data base containing precise details of the city's street trees, have together impeded the growth and management of street trees. Moreover, a weak institutional capacity characterized by staff shortages and the lack of trained staff, the absence of any regular follow-ups and protective measures, the poor selection of tree species, the lack of norms and standards regarding exactly where street trees should be planted, traffic accidents, and the installation of utilities, are all factors impeding proper street tree development and management.

As far as regards local strategic practices, while cooperative housing green areas are developed and managed by the members of cooperatives and *Iddirs*, the study reveals that this strategy is ineffective due to the lack of awareness and of property deeds relating to the green areas in question. On the other hand, street trees are grown and managed by the sub-city's BPCDM offices and Woredas, with the involvement of other stakeholders; however, this strategy has been poorly implemented and has been significantly constrained by a general lack of awareness, by insufficient follow up by the BPCDM experts in question, and by the absence of incentives to volunteers.

The study also found that there is a general lack of stakeholders' participation in the planning, development and management of these spaces. However, the Federal Democratic Republic of Ethiopia's Constitution, the Environmental Policy of Ethiopia, the Urban Development Policy, and Urban Planning Proclamation no. 574/2008c, all contain general provisions regarding the development and management of urban green areas by the stakeholders in question. The study also revealed that BPCDM's recently formulated enforcement manual, together with the office's intra and inter-sectoral links, represent good opportunities for the sector to implement green development and management projects in a coordinated manner. The involvement of housing cooperative members in the development and management of their own green areas, together with the recent establishment of private partnerships to develop and preserve street trees, are also deemed positive measures and practices.

REFERENCES

Abeje, W. (2006). What an Urban Livelihood without Adequate Breathing Space? A Reflection on the Green Areas of Addis Ababa. In *Proceedings of Green Forum Conference on Environment for Survival* (pp 1-14).

Balram, S., & Dragicevic, S. (2005). Attitude towards Urban Green Spaces; Integrated Questionnaire Survey and Collaborative GIS Techniques to Improve Attitude Measurement. *Elsevier: Landscape and Urban Planning*, *71*(2-4), 147–162.

Bartone, C., Bernstein, J., Leitman, J., & Eigen, J. (1994). Toward Environmental Strategies for Cities: Policy Considerations for Urban Environmental Management in Developing Countries. Washington, DC: the World Bank.

Baycan-Levent, T., & Nijkamp, P. (2004). Planning and Management of Urban Green Spaces in Europe: Comparative Analysis. *Journal of Urban Planning and Development*, *135*(1), 1–12. doi:10.1061/(ASCE)0733-9488(2009)135:1(1)

Beer, A., & Jorgensen, A. (2003). New Approach in Europe. In *Decent Homes Decent Spaces*. Retrieved from http://www.neighbourhoodsgreen.org.uk/upload/public/documents/webpage/dhds%20reduced.pdf

Belay, A. (2002). *Green Frame Development Study*. Ministry of Federal Affair AAIDPO.

CGAA. (2011). *Guide Line for Beautification and Park Development and Management Core Process*. Addis Ababa.

European Commission. (2007). *Integrated Urban Environmental Management: Guidance in Relation to the Thematic Strategy of Urban Environmental Management*. Retrieved from http://ec.europa.eu/environment/urban/pdf/iem.pdf

European Commission. (2014). *Mapping Smart Cities in the EU*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

FDRE. (1995). The Constitution of the Federal Democratic Republic of Ethiopia. *Proclamation No*, *1/1995*, 1–38.

FDRE. (1997). *The Environmental Policy of Ethiopia* (p. 15). Protection Authority.

FDRE. (2008). Urban Planning. Proclamation No. 574/2008c (pp. 4067-4085).

Giffinger, R. (2007): *Smart cities, Ranking of European medium-sized cities*. Retrieved from http://www.smart-cities.eu/download/smart_cities_final_report.pdf

Haile, F. (2003). Environmental Planning in the Context of Urban Planning in Ethiopia: Existing Practice and Prospects. In *Proceedings of National Conference of Urban Planning and Related Issues* (pp.113-115). National Urban Planning Institute.

Horst, A. (2006). Rehabilitation of Urban Forest in Addis Ababa. *Journal of the Dry Land*, *1*(2), 109.

Irum, S., Alamgir, M., Gul, M., & Osman, A. (2002). Perceptions of Community in Madina Town Towards the Undeveloped Green Spaces in Madina Town. *Pakistan Journal of Applied Sciences*, *2*(12), 1099–1101.

Ministry of Federal Affairs. (2006). *Urban Development Policy*. Addis Ababa, Ethiopia.

NSLSC. (2011). *BPCDM Office Annual Report.*

NSLSC. (2011). *BPCDM Office Street Trees Inventory Report.*

Oguz, D. (2000). User Survey of Ankara's Parks. *Elsevier Science: Landscape and Urban Planning*, *52*(2), 165–171.

ORAAMP. (1996). Addis Ababa in Action: City Development Plan 2001-2010. Addis Ababa, Ethiopia.

ADDITIONAL READING

Aldous, D. E. (2010). Greening South East Asian Capital Cities. In *Proceedings of 22th IFPRA World Congress*.

Baycan-Levent, T., & Nijkamp, P. (2009). Urban Green Space Policies: Performance and Success Conditions In European Cities. In *Proceedings of 44th European Congress of European Science Association* (pp. 2-3). Portugal.

Benedict, M., & McMahon, E. (2000). Green Infrastructure: Smart Conservation for the 21st Century. Retrieved from http://www.sprawlwatch.org/greeninfrastructure.pdf

BWUD. (2001). *Draft Guideline of Green Areas, Amharic document*. Addis Ababa: Bureau of Work and Urban Development.

Byryne, J., & Sipe, N. (2010). *Green and Open Space Planning for Urban Consolidation – A Review of The Literature And Best Practice*. Retrieved from http://www98.griffith.edu.au/dspace/bitstream/handle/10072/34502/62968_1.pdf

Carmona, M., De Magalhaes, C., & Blum, R. (2004). *Is the Grass Greener? Learning from International Innovations in Urban Green Space Management*. Retrieved from http://webarchive.nationalarchives.gov.uk/20110118095356/http:/www.cabe.org.uk/files/is-the-grass-greener-full.pdf

Chen, Z. (1999). Urban Landscape Gardening and Sustainable development: In *Proceedings of IFPRA-Asia/Pacific Congress* (pp. 22-26). Hangzhou, China.

Dunnett, N., Swanwick, C., & Woolley, H. (2002). *Improving Urban Parks Play Area and Green Spaces*. Retrieved from http://webarchive.nationalarchives.gov.uk/20120919132719/http:/www.communities.gov.uk/documents/communities/pdf/131021.pdf

Kuchelmeister, G. (2000). *Trees for Urban Millennium: Urban Forestry Update*. Retrieved from http://www.fao.org/uploads/media/Trees_for_the_urban_millenium_urban_forestry_update.pdf

Kumilachew, T. (2007). Critical Assessment on the Current Operation of Planned Public Open Spaces in Addis Ababa's Urban Environment: The Case of Meskel Square and Leghar Park. (Unpublished MSc Thesis). Addis Ababa University.

Nayeem, M. (2008). *Peri-Urban Forestry and Greening in Bangladesh: Dhaka City as a Case*. (Unpublished MSc Thesis).

Strohmayer, U. (2006). Urban Design and Civic Spaces: Nature at the Park Des Buttes-Chaumont in Paris. *SAGE Journals. Cultural Geographies*, *13*(4), 557–576. doi:10.1191/1474474006cgj375oa

Suomalainen, S. (2009). A Comparative Study of Urban Green Area Planning. (Unpublished MSc Thesis). University of Helsinki.

The Scottish Executive Central Research Unit. (2011). *Rethinking Open Space*. Retrieved from http://www.scotland.gov.uk/Resource/Doc/156814/0042172.pdf

William, R. (2000). Environmental Planning For Sustainable Urban Development for Caribbean Water and Wastewater Association. In *Proceedings of 9th Annual Conference & Exhibition*. Chaguaramas, Trinidad.

KEY TERMS AND DEFINITIONS

Challenges: Constraints that act as a bottleneck for the development and management of cooperative housing green areas and street trees in Nifas Silk Lafto Sub-city.

Community Based Organizations: This term denotes Iddirs and local business communities.

Cooperative Housing Green Areas: The green areas of cooperative houses that were built during the Dergue regime and by the current government through the adoption of a self-help approach in Nifas Silk Lafto Sub-city.

Local Strategic Practices: Refers to a set of actions designed to improve cooperative housing green areas and street trees in Nifas Silk Lafto Sub-city.

Opportunities: Refers to the initiatives and actions taken by the stakeholders to enhance the development and management of cooperative housing green areas and street trees in Nifas Silk Lafto Sub-city.

Stakeholders: Refers to those actors, including government institutions, communities or community-based organizations, and voluntary groups (NGOs), that are responsible for the development and management of cooperative housing green areas and street trees in Nifas Silk Lafto Sub-city.

Street Trees: Refers to trees planted both at the sides of roads and along median strips in Nifas Silk Lafto Sub-city.

Urban Green Area Development: Refers to improvement to cooperative housing green areas and street trees designed to maximize their benefits for urban life in Nifas Silk Lafto Sub-city.

Urban Green Area Management: Refers to the preservation and protection of cooperative housing green areas and street trees so as to meet the intended objectives in Nifas Silk Lafto Sub-city.

Woreda: District-level administrative unit.

ENDNOTES

[1] Office for the Revision of the Addis Ababa Master Pan

[2] Nifas Silk Lafto Sub-city

[3] Nifas Silk Lafto Sub-city Beautification, Park and Cemetery Development and Management

[4] Oguz (2000), Ibid., pp.165-171

[5] E.C. (2007), Ibid., p. 7

[6] Officers from the design and construction management office, the land development bank and urban renewal office, the urban plan preparation and information office, the land development and ownership administration office, the BPCDM office, the environmental protection authority office, and the code enforcement office of the Woredas in question and of Nifas Silk Lafto Sub-city, were interviewed.

[7] Social organizations established by the communities in order to resolve various social problems.

[8] The land development bank and urban renewal office, urban plan preparation and information office, land development and ownership administration office, design and construction management office, environmental protection office, water development office, and justice office, at different municipal administrative levels, are the institutions responsible.

Chapter 6
Living Labs and Urban Smartness:
The Experimental Nature of Emerging Governance Models

Grazia Concilio
Politecnico di Milano, Italy

Francesco Molinari
Politecnico di Milano, Italy

ABSTRACT

Urban Living Labs are socio-digital innovation environments in realistic city life conditions based on multi-stakeholder partnerships that effectively involve citizens in the co-creation and co-production of new or reformed public services and infrastructures. This chapter explores the growing phenomenon of Urban Living Labs and analyses the nature of related innovations in the perspective of 'City Smartness' – a mantra for local governments worldwide which are having to address increasingly complex problems with fast diminishing financial resources. It goes on to briefly overview the urban governance models emerging in such environments and finally focuses on the challenges posed by these models as result of integration between the 'technology push' Smart City vision and the 'human pull' Urban Living Lab concept and approach.

INTRODUCTION

Public sector organisations worldwide increasingly need to rely on innovative multi-stakeholder partnerships to address more and more complex problems with fewer and fewer resources. This basic tenet has become pervasive in many areas of policy-making, both at theoretical and practical level. During an expert meeting held on 20th January 2009, the President of the European Commission J. Manuel Barroso declared: 'The financial and economic crisis makes creativity and innovation in general, and social innovation in particular, even more important to foster sustainable growth, secure jobs and boost competitiveness'. In the background of this declaration,

DOI: 10.4018/978-1-4666-8282-5.ch006

the Renewed Social Agenda launched on 2nd July 2008 by the Barroso Commission aimed to deal with a fast-changing European scenario shaped by globalisation, technological progress, ageing societies and people at risk of exclusion. Since 1991, when it was started as a separate Community Initiative, the LEADER approach has been providing rural communities in the European Union with a method for engaging local partners in shaping the future development of their area. The acronym 'LEADER' stands for the French 'Liaisons Entre Actions de Développement de l'Économie Rurale', which means 'Links between rural economy and development actions'. The idea was to enlist the energy and resources of people and bodies that could contribute to the rural development process by forming partnerships at sub-regional level between the public, private and civil sectors (European Commission, n.d.). In the programming period 2014-2020, the LEADER approach will be referred to as 'Community-Led Local Development' (CLLD) and jointly supported by several Structural funds (European Commission, 2014), as it is possibly extended to other communities beyond the rural. 'Community' here does not only mean individual residents and beneficiaries of funded actions, but also voluntary and community organisations, local authorities, other public bodies and agencies, and local private sector businesses. Likewise, the World Bank's 'Community Driven Development' (CDD) approach gives control to local groups over planning decisions and investment resources addressing development related issues. 'Experience has shown that when given clear explanations of the process, access to information and appropriate capacity and financial support, poor men and women can effectively organize to identify community priorities and address local problems by working in partnership with local governments and other supportive institutions' (World Bank, 2015). In a nutshell, the CDD approach leverages 'on the principles of local empowerment, participatory governance, demand-responsiveness, administrative autonomy, greater downward accountability, and enhanced local capacity'.

Many researchers in the context of cooperation for development have explored the impact of social innovation on traditional public services. For example, a study by SERCO (2012) showed that over the past 60 years in India, social enterprises have stepped in to address the challenges that the government was leaving unmet. As a result, radically new perspectives have emerged based on a limited intervention or involvement of the State in public affairs. Even in the more advanced economies and societies, 'user empowerment', as opposed to 'user centred' delivery of services, has been proposed in response to a number of global trends, such as increased individualism, extended mobility, improved living standards, and no less important, a massive expansion and pervasiveness of Information and Communication Technologies (Osimo et al., 2007).

In this context, the Urban Living Lab concept (Juujärvi & Pesso, 2013; Concilio et al., 2014) has been proposed as a socio-digital innovation environment based on multi-stakeholder partnerships that are framed within a City or Neighbourhood context. 'An Urban Living Lab involves partners representing more than one sector of society other than academia, e.g. a municipal government, a private company, or a non-governmental organization. It is a forum for research and discovery, that by its design is open for learning and exploration in any direction, between any combination of participants' (JPI Urban Europe, 2013).

This chapter reflects on the forms of innovation emerging in Urban Living Labs and analyses the relevance they can have in shaping a City's Smartness. Associating Living Labs with Smartness is not straightforward: in fact, the prevailing definition of a Smart City implies 'the strategic adoption of ICT and Future Internet based tools, networks and applications to provide services to citizens or to manage (urban level) infrastructure' (Webb et al., 2011). In contrast, the Human Smart City vision (Concilio et al., 2013) enriches the original concept with lessons learnt from the application of citizen-centric and participatory methods to co-design and co-experiment innovative urban services together with their prospective beneficiaries. In this respect, the very essence of the Living Lab approach (namely to empower and engage end users from the early stages of product/service development in real-life conditions) qualifies and embodies itself into a socio-digital collaboration of 'people in places'. This leads to a more advanced notion of Urban Smartness (Concilio et al., 2011), which becomes the ability of local governments to experiment and learn from within the complex dynamics of sociotechnical networks and to check continuously the coherence between micro-scale innovations and macro-scale visions.

Dealing with such aspects also entails bringing the issue of governance (in general) and ICT driven governance (in particular) into the focus of Urban Living Lab research and practice, both in association with the structuration of service experiments (trials) and the 'legitimization' of results obtained in the broader context of urban and territorial policies (Molinari, 2011).

The chapter is structured as follows: section 2, the following one, explores the growing phenomenon of Urban Living Labs and analyses the nature of related innovation in the perspective of Urban Smartness; in section 3 we briefly discuss the urban governance models emerging in such environments; and finally in section 4 we focus on the challenges these models pose for local governments worldwide, particularly those willing to integrate the 'technology push' Smart City vision with the 'human pull' Urban Living Lab concept and approach.

THE 'SMART SIDE' OF URBAN LIVING LABS

Known Typologies

Juujärvi and Pesso (2013) distinguish at least three typologies of Urban Living Labs. Within the first typology, citizens give feedback on urban products, services and policies (such as housing or environmental transformation) through webpages or sensor-based methods. Therefore, they act as 'technology-assisted research environments'. Within the second typology, users are mobilized to co-create urban artefacts and local services, such as communal yards, garden allotments, or daycare services. We can call these 'grassroots or social innovation environments' (the definition is ours). In the third typology, citizens are engaged in new kinds of urban planning through innovative tools that facilitate visioning and processes, integrating stakeholders in public decision-making. We can call these 'participatory planning environments' (again, the definition is ours). However, the boundaries of the different Urban Living Labs may be blurred or overlapping according to the Authors, e.g. due to simultaneous participation and collaboration of the same local stakeholders in multiple contexts and for the attainment of multiple goals.

While it is certainly useful to cluster and identify the known experiences of Urban Living Labs according to their purposes and prevailing processes, we think this only partly grasps the breadth and subtlety of the underlying innovation phenomena. In fact, innovation in Urban Living Labs is spatialized, i.e. generated 'within' a specific spatial environment, not necessarily 'for' it, although in many cases the improvement of the context is the main aim of the initiative. The scale of these innovations is probably smaller than the urban; nevertheless they allow public decision makers to draw lessons and figure out prospects for systemic changes at city level; quite often they also provoke viral dynamics and effects that move innovation from the micro (individual or group) to the larger (meso-neighbourhood, or macro-urban) level.

It Happens in Cities

More and more often we are witnessing the birth and diffusion of citizen initiatives that, rooted in the micro-scale, denote a renewed kind of activism, often driven by the collective intention to act on behalf of the conventional powers in charge of governing the City. This phenomenon is not recent, but surprisingly it is growing: in addition to the *guerrilla gardeners* movement active since the '70s, many others are emerging from the inside out – such as the *bikelane builders* or the *depavers*. Most of these initiatives are oriented to physical transformation of the City, but some are also intervening in mobility flows (such as the wide movement of citizens joining the *pedibus* initiative or the *blablacar* carpooling system*)* and others are remaking the immaterial resources of a City (such as the fast-spreading *social street* projects).

In many cases, the initial impulse to engage in these activities comes from the perception of shared problems, by people who agree to put common resources into a collective problem-solving effort. Not necessarily identifiable as answers to welfare needs, they can be intended as 'new ideas that meet unmet needs' (Moulgan, 2007). They are spontaneous processes with good potential for achieving radical change; many are planned, some are unplanned, all are driven by a collective 'will' that, while being difficult to analyse, is characterized by self-awareness and therefore suitable to be turned into action. They are 'insurgent' phenomena that can sometimes trigger long-term dynamics of transformation, meeting the social, political, economic and cultural challenges faced in the urban community.

The stories collected by Jeffrey Hou (2010) on 'Guerrilla Urbanism' offer a clear understanding of the way in which the spatial dimension affects and shapes these renewed manifestations of activism. Urban 'places' are no longer simple localisations (either physical or not) of contestation rather than civic engagement events. They are substantially recreated, not only physically but also culturally, through self-produced spaces, temporary events, or even flash mobs. They are re-appropriated by the very people who were supposed to 'own' them, but do not – the citizens – due to a variety of reasons related to the structure of power and social relationships established in the City.

This effervescence is giving birth to a new sense of 'urban'. Rarely being the simple output of intentional design, urban activism is (re)conquering the core of citizens' presence and role in the community, with actions that are innovating consolidated protocols of civic participation, from saying/discussing to making/acting (Concilio et al., 2014). In these case studies a new way of 'making' the City is emerging: the City is no longer designed, it is rather 'experimented'; the City is not a service offered to citizens, it is rather (re)created by the citizens through experiments on places, flows and infrastructures.

What Kind of Innovation Is This?

The identification of some common characteristics of such processes helps us to refine the concept of 'urban innovation'.

The dynamics observed in many urban realities confirm the existence of important innovation energies. These energies are manifested mostly at the sub-urban scale, neighbourhood or community, even small groups of individuals. Innovation targets are associated with a collective, spatialized, and localized will, that is unable to distinguish between the 'private' and the 'public', or better, is able to integrate the 'private' and 'public' within a broader vision of 'citizenship making'.

In these environments innovation always takes on a socio-digital nature: it is enabled by existing technologies when they are considered suitable for the attainment of collective goals (see the use of Facebook for the large movement of *social streets*) or driven by technologies developed 'ad hoc' as tools for solving a targeted problem (see for example the development of the *blablacar* platform). Normally it is difficult to distinguish between these two dimensions, the social and the digital (see Kaletka et al. (2011) for a discussion of this), instantiating a dialogue that is collaborative and reciprocally constructive, rather than competitive, during the search for a solution. In most of these cases what we observe is the development of a socio-digital infrastructure working as a pathway towards innovation in the 'urban', considered either a modification of an existing service/solution/process or the implementation of a completely new one.

Does This Innovation Feed Urban Smartness?

The phenomena described above seem to suggest another promising research strand for Urban Living Labs literature: they are showing the possibility of conceiving a Smart City as a real-life, diversified and integrated experimentation environment.

Some key issues need to be addressed here. A City that experiments is:

- Able to capture and cooperate with the *innovation insurgences* emerging in response to citizens' concrete needs; innovation insurgences are the spontaneous 'experimentation labs' that many communities are already offering to the collective knowledge;
- Able to activate collective *experimental environments* where knowledge is not a competitive advantage tool, but rather a public good; these environments are not isolated but organized as nodes of a learning network, able to make the experiments of others their own;
- Able to give life to *bottom-linked institutions* (Moulaert, 2010) that can sew, structure and densify the relationships between citizens and governments;
- Able to (re)create itself through the activation of areas in which rules can be temporarily suspended and new ways of 'city making' can be experienced.

Far from being a new model, this idea of focussing on the experimental dimension of innovation in and by Cities and communities is a way of looking at Smartness not as an end, but rather as a way forward.

It is exactly the process that Nam and Pardo (2011) consider key towards Smartness; if we accept their idea of a Smart City 'not as a status of how smart a city is but as a city's effort to make itself smart' (p. 186), it becomes clear that Urban Living Labs are the most appropriate instruments for cities to develop their Smartness in a way that is not focussed on the technological solutions, but rather driven by collectively shared problems, although Living Labs are not often identified as drivers or producers of a City's Smartness.

Rephrasing what Nam and Pardo propose as a definition of a Smart City, the socio-digital innovation associated with Urban Living Labs is developed in urban settings, i.e. in a place-based and community sensitive way. In this sense it challenges the idea of an easy way of becoming Smart: the implementation of innovative technologies is only part of the story, and not even a relevant one. The real innovation lies in the way communities deal with and feel positively challenged by such technology.

Urban Living Labs are certainly not a comprehensive answer to the incredible number of issues that cities are called to respond to nowadays. They are rather laboratories for finding out (quoted by Nam and Pardo, 2011) 'novelty in action' (Altschuler & Zegans, 1997) and 'new ideas that work' (Mulgan & Albury, 2003).

They are laboratories where Cities can experiment their own (spatialized) Smart solutions without putting at risk huge amount of resources with comprehensive and large ICT infrastructuring programs. They are environments considering SMARTNESS a careful, gradual, stepwise, and diversified (not the same for all City places, not unique or standard for all Cities) socio-digital innovation process, where learning happens as the result of distributed, collective experimentations.

This way of learning is also eminently public and social, therefore broader and more encompassing than the 'distinctive method of knowledge production' emphasized by Juujärvi and Pesso (2013) in their outstanding analysis of Urban Living Labs. While these Authors focus on innovators 'learning by doing' as a heterogeneous, diffuse, and transient-by-nature method of knowledge production, organized around a particular application, we prefer to adopt the triple-loop learning concept (Concilio & Molinari, 2014) and relate it to the transformational shifts in what people, groups and communities view as desirable innovations or changes in current ways of living. This vision implies that a process of reflection and questioning, rather than mere information usage or provision, lies at the heart of any systemic change.

LIVING LAB DRIVEN MODELS OF GOVERNANCE

In the previous section, we proposed that a City can be defined as Smart if it is able to think and manage itself like a complex environment of interdependent experiments, where solutions are developed (i.e. designed, prototyped, tested and implemented):

1. To solve real-life problems and respond to its citizens' concrete needs;
2. In collaborative, participatory and learning environments;
3. At the micro or meso scale where problems themselves are located, although being aware of the scalar and institutional dependency of urban actions;
4. With learning at macro scale being guaranteed because experiments are considered public/collective goods.

Having identified Smartness as the way rather than the result, the issue of governance now clearly comes to the forefront, intended as the ability to both manage the Urban Living Lab's innovation trials, processes, actors and results successfully, as well as framing and scaling the experimentation outputs up to the broader context of urban services and policies.

Innovation and Governance

The relation between new forms of governance and innovation in urban settlements has not been widely analysed. Nevertheless, since local authorities cannot do much alone to resolve the complex problems they are challenged by, the involvement of all stakeholders, and the promotion of Public-Private-People Partnerships (4Ps) within a participatory governance framework is required when trying to innovate urban services that can meet these challenges.

Traditionally, the supply of public services is associated with two types of actors: public or private. Over the past forty years, the fragmentation of public services initiated by the New Public Management revolution has opened the possibility of creating innovative business alliances to support and guarantee their delivery. This has paved the way towards establishing Public-Private Partnerships (3Ps) for service provision, which have proven especially appropriate for securing economic, social, and community development goals.

Evidence from the deployment of urban services has shown that the most effective partnerships of the 3P kind can be considered as effective forms of governance, firstly because they can build collective responsibilities pertaining to the combined process of activity development: planning, decision-making, problem solving, project implementation and evaluation. In many instances they have also managed to create networks of relevant stakeholders who share knowledge, resources, and common goals. Finally, 3Ps have often served as catalysts for sustainable community dialogue, integrated solutions, and long-term local change. A flexible design and a constant feedback mechanism have proven critical for their success in innovating. To summarise, Public-Private Partnerships have been considered effective tools for participatory innovation governance because they can account for both (i) the activity and its resolutions and (ii) the implications of innovation on broader community development.

According to Paskaleva (2001), 'the concept of partnerships is the cornerstone' for participatory governance to foster innovation. Generally described as a 'mechanism allowing the mobilisation and co-operation of a great number of actors in order to mould the necessary political and operational consensus to affect directly the everyday life of all members of society', 3Ps embody many advantages which are coincident with the currently acknowledged main criteria for sustainability; they require consideration of multiple stakeholders' interests, imply a long term perspective based on common goals, and can accommodate a wide range of conflicting perspectives (Paskaleva, 2001).

What is also shared is that whatever the form of partnership, no good governance exists unless a few basic principles are adopted and enforced in practice, which the United Nations (2008) listed as follows: participation, decency, transparency, accountability, fairness, efficiency, and sustainable development.

Innovation can only be fruitfully developed under the above mentioned principles; nevertheless, their operationalization in whatever form of partnership requires that governance is the goal, not the by-product, of a process recognizing that decisions are made on the basis of complex relationships between many actors with different and sometimes conflicting priorities.

The emergence of the 4P model, which is connatural to Urban Living Labs and Living Labs in general, can also be explained after the realisation of the 3P scheme's limit, having failed to compensate for the loss of power and representation in the perspective of government, with a more inclusive and careful consideration of the requirements and expectations of constituents in terms of engagement and participation.

The perspective of socio-digital innovation outlined above consistently needs a more advanced concept of networking and collaboration, which the Public-Private-People Partnership (grounded on mutual recognition and acknowledgement of rights and duties) is possibly able to ensure.

Openness and Governance

Urban Living Labs as innovation partnerships can be analysed across the dynamic relationships that involve diverse actors, based on mutually agreed objectives, and the actions pursued through a shared understanding of the most suitable distinction of roles and reciprocal benefits.

According to Brinkerhoff's (2002) literature overview, two dimensions are salient to define partnerships and distinguish them from other relationship types: Mutuality, encompassing the spirit of partnership principles; and Identity, capturing the rationale to select particular partners. 'Mutuality can be distinguished as horizontal, as opposed to hierarchical, coordination and accountability, and equality in decision-making, as opposed to domination of one or more partners. (…) Identity generally refers to that which is distinctive and enduring in a particular organization'.

Their preservation lies at the basis of a partnership's added value according to this Author.

While the two former dimensions are confirmed as relevant within known Urban Living Lab experiences, a third one can be observed as crucial: Openness.

Again, it is well understood that the paradigm of Open Innovation (Chesbrough, 2003) is a key element of any known Living Lab (Pallot, 2009). However, our vision of Openness directly affects the process of experimentation and results generation, rather than merely the intellectual property rights on the outputs generated.

Urban Living Labs are environments in which the openness of innovation manages to transcend the organizational infrastructures that are traditionally operating in the city and invent new institutional figures for, or ways of, dialoguing between citizens and institutions. Here openness is enhanced by a dynamic nature that is revealed through new forms of temporary alliances (adopting the 3P or 4P model) that, not only based on formal agreements, are embedded, hinged in the action: better when it is collective, for action itself becomes the measure of mutual transient or long-term commitment that each actor can guarantee. This implies that both public and private sector stakeholders should be available to experiment new forms of collaboration and interaction, which are capable of shaping the necessary organizational environments. In fact, the activation and maintenance of Urban Living Labs also require the exploration of new institutional or political roles and structures, thus allowing for innovative communities to be formed.

Yet in these environments, Openness also guarantees experimental approaches ranging from small practices intervening in the city to the experiment-based development of urban transformation policies. The problem-driven processes taking place in Urban Living Labs are fundamental to activating such experiments of networking between citizens, public authorities, and ICT suppliers. In turn, the networking itself evolves along experimentation trials, thus keeping the process open over time and increasing the opportunities for innovation.

Extant literature mostly takes a static perspective as consistent with the concept of governance partnership, while a co-evolutionary perspective of partnership dynamics has only recently started to be investigated in some domains (De Reuver, 2009). This perspective has been proven in the Periphèria project (Periphèria, 2013), as the only one possible in open innovation environments such as Urban Living Labs. Periphèria was a 30-month pilot funded by the European Commission under the CIP ICT PSP Programme in 2011. Its main objective was to deploy convergent Future Internet platforms and services for the promotion of sustainable lifestyles in and across emergent networks of 'smart peripheral' cities in Europe. The pilot elaborated on the Living Lab premise of shifting technology out of R&D laboratories and into the real world in a systemic blend of technological with social innovation. In so doing, it defined six archetypical Arenas – specific sub-urban settings or innovation playgrounds, with defined social features and infrastructure requirements – as spaces of election for the co-design and service integration processes to unfold:

- Smart Neighbourhood: where media-based social interaction occurs
- Smart Street: where new transportation behaviours develop
- Smart Square: where civic decisions are taken
- Smart Museum and Park: where natural and cultural heritage feed learning
- Smart City Hall: where mobile e-government services are delivered
- Smart Campus: where formal and informal knowledge meet for urban renewal.

Six European Cities – Malmö (SE), Bremen (DE), Athens (EL), Genoa (IT), Palmela (PT) and Milan (IT) – engaged in developing and structuring these Urban Living Lab spaces to stimulate social interaction, cross-city linking of Arenas and discovery-driven establishment and convergence of services. Transfer scenarios were developed with six additional sponsoring cities, to validate the upscaling and sustainability potential of the smart services co-created. A feature common to all these services is that they enriched the original concept of Smartness with a human driven perspective, gained through the application of citizen-centric and participatory co-design methods. This also helped clarify that a 'technology push' concept of smartness alone – installing sensors, meters, infrastructures – to meet public service improvement goals was under serious risk of failure as it placed the citizen outside of the process, not allowing him/her to take ownership of the need, rationale and justification for introducing and sustaining change.

One of the lessons learnt from the project is that, when Openness is key to innovation and the role of civil society is stressed as in Urban Living Labs, a dynamic transitioning of the 4P model is required and needs a consistent formulation to be found (as already envisaged by Hellström Reimer et al., 2012).

Urban Living Labs do not only call for Public-Private-People Partnerships (Verilhac et al., 2012), they also show that there is a need to re-conceptualize these partnerships in the direction of Openness, thus asking for partnerships that are able to contemplate a fluid, dynamic networking, in which trust and ethical value assume a contractual power among participants (Blomqvist, 2002).

Periphèria proved some partnership strategies to be effective for such a fluid, dynamic networking to occur, namely:

- Continuous interests/resources alignment (flexible work plan and allocation of resources)
- Continuous dialogue and facilitation of interactions towards match-making (value sharing and creation)
- Top-down/bottom-up initiative coordination
- Keeping a long-term perspective (vision consistency) and trust/confidence building
- Synchronizing activities among different and dynamic parties and actors

This approach does not exclude the importance of formal protocols or agreements, which are always considered fundamental means of capturing relevant cooperation and collaboration actions inside the above mentioned dynamic and fluid networks. Formal protocols and agreements may assume the value of 'partnership chunks' to be integrated ("patchworked") with others, arising in different forms and times, all together formally architecturing the fluid networking without putting the openness of the innovation system at risk.

WHICH CHALLENGES FOR PUBLIC ADMINISTRATION?

To sum-up, the governance of Urban Living Labs can be seen as the architecture of an eco-system of open and dynamic partnerships emerging and dismantling in response to precise spatially-framed needs and coherently with contextual conditions (political, cultural, economic, and participatory), acting as both drivers and constraints. Its main task, for the reasons expressed above, is to ensure a proper balance between the commitment and self-interest of the relevant and involved stakeholders.

The main challenge that local public administration is called upon to deal with is related to the increasingly highlighted need and importance for a City to activate, attract, manage, and support innovation. How to strengthen, or better, develop the existing capacity towards an 'extended' concept of Smartness? As Louis Albrechts (2013) recently reiterated: 'More of the same is not enough!' Or no single-case evidence or isolated answer or solution, however bright and/or general it may seem, would be enough.

In apparent contrast to this perception, the references to Urban Guerrillas and the new forms of Civic Activism mentioned above suggest that the sub-urban (micro) scale of Living Labs is where the skills and energies of innovation should be fostered, activated, procured. It is at this scale that it seems possible for a City to experience multiple, diverse, but coherently smart solutions. It would seem, therefore, that the most significant challenge for local governments is precisely to be able to look at the City as a large, however complex, experimental laboratory to which every Living Lab (community) is called to contribute.

In many Urban Living Labs, it is possible to observe that local government actors are involved in different ways: they are asked to approve, support, or collaborate actively with the constituents and their degree of engagement varies from very slight (for example, in those cases where the assigned role is limited to sponsoring some initiatives) to very extensive (whenever assumed responsibilities are coupled with important resource investments and even complex public decisions).

While it is easy to recognize that the local public administration is a key stakeholder inside any Urban Living Lab environment, it is not as easy to understand whether, and to which extent, policy makers and civil servants should look at Urban Living Lab experiences as important contributions to the development of City Smartness. In most cases, it seems that there is little institutional awareness of this direction. This lack of awareness may depend on the small scale of experimentation; it may also derive from the cultural distance of many of these initiatives from the most widespread (widely accepted) concept of urban smartness.

The challenges facing local governments can therefore be summed up in one question: how can a public administration take advantage of the learning opportunities offered for the urban scale by the numerous, smart, innovation initiatives that are not limited in their potential by occurring at sub-urban scale? Adding a ‘human pull’ Urban Living Lab concept and approach to the ‘technology push’ Smart City vision is simply not enough. A city that is smart, or able to innovate, is also capable of civic intelligence (Schuler, 2013), i.e. prone to experimentation and learning in a transparent and collective way. It is probably in this direction that local governments need to rethink their role and approach towards smartness and innovation.

CONCLUSION

Many Cities worldwide are developing their Smart Agendas; some of them are using significant resources in implementing technological solutions for innovative community services. Despite this global ‘fever’, we remain sceptical that interpreting the concept of urban smartness in a way that is technology-pushed rather than human-driven may allow us to grasp the full potential of Urban Smartness.

Starting with a reflection on several grassroots episodes of civic engagement and collective action for urban transformation, this chapter has tried to qualify existing definitions of Urban Living Labs by putting more emphasis on place-based collaboration, eco-systemic dynamics and the role of governance models in eliciting and supporting innovation.

Many innovation forces are active in urban environments; these forces are often aligned with the most recent concepts of crowdsourcing and open collaboration and suggest very far-looking modes for city ‘making’, involving citizens in the activation of change, sometimes radical change as well. In this respect, local public administration is called to act to enable, legitimize, and support the constructive interaction of citizens and stakeholders. In so doing, new and original forms of government and governance can emerge, which the proposed chapter has proposed to reflect on.

A full perspective on managing and governing a Smart City conceived as a patchwork of sub-urban innovation experiments implies in practice that at least three areas of local government action need to be rethought: 1) regulations, 2) policies and 3) modes of interaction and agreement with citizens and private actors.

Many activities in the space of a city are governed by a system of rules that, in many cases, do not appear adequate to guarantee some of the forms of innovation addressing our definition of Smartness; these have started to emerge in cities, somehow challenging the existing rules and regulations. Without compromising the value of social and collective rules, public authorities are increasingly being asked to find out how to develop new rules, or forms of rules, that are able to consider the legitimacy, at least temporary (consistent with the experimental approach of Urban Living Labs), of ways and forms of action within the city considered unusual until today.

This reflection on rules does not differ much from a reflection we might start on urban management and transformation policies; it only and obviously becomes more complex due to the link which policies often build with value systems. A truly experimental nature of policy-making requires a significant integration of these two focuses: the policy object and the policy process, the policy goals and the policy-making. This requirement was already evident in the reflections of Pierluigi Crosta (2006), but it is now enhanced by a strategic significance of the notion of 'value creation', which goes beyond the more usual (and sometimes prevailing) perspective of 'value guarantee'. The possibility of experimenting at both regulation and policy-making level inexorably imposes a rethink of ways to manage and deal with the relationships between governments, citizens and private actors, i.e. with the governance concept per se.

Finally, there are already many formal devices that substantiate different or alternative modes of interaction and agreement between different subjects, and this somehow helps fulfil the third area of innovation required for the operation of public administration. Experience, however, has shown that when interaction happens in an experimental environment, a lower degree of formalisation for these agreements is preferable. However, whenever contracting is less binding or non-existent, the accountability mechanism is no longer guaranteed. Therefore, it is necessary to imagine new forms of 'collective responsibility' purposeful action in the public sphere that does not mortify innovation initiatives such as those now emerging in cities.

Many local governments have started to implement their Smart Agendas, but many others are only now figuring them out, since they are still outside of the 'smart urban adventure'. Whatever their awareness or level of development of this Agenda, all cities are facing an incredible mix of serious challenges arising from the problems that modernity has created and does not seem able to resolve. The environmental, political, social, financial, and cultural are all dimensions of the current crisis that, it is widely believed, can only be fully faced in and by the cities, and hopefully reduced to more manageable problems. Therefore, the Smartness rhetoric, if correctly understood as a mix of human and technological, urban and sub-urban, city and cross-city resources, actions and pathways, can contribute to forming collective awareness and promoting the necessary changes, both strategic and operational, in the direction of sustainability. This certainly requires a great deal of innovation and the mobilisation of all positive energies available in the civil society.

Urban Living Labs can be one of the new assets to be leveraged at the service of defining smart responses to global and local crises. We are confident that policy makers and civil servants will soon acknowledge the need to abandon old fashioned visions and fully embrace new and promising models of governance that are strongly emerging from the grassroots, not to become dependent on the 'tyranny of innovators', but to foster and enable real and concrete prospects of change based on the most flourishing and promising engagement and collaboration examples.

REFERENCES

Albrechts, L. (2013). Presentation at the Round Table on Co-design for social creativity. *Human Smart Cities session at FORUM PA*, Rome.

Altschuler, A., & Zegans, M. (1997). Innovation and public management: Notes from the state house and city hall. In Althschuler, A. & Behn, R. (Eds.) Innovation in American Government. Washington, DC: Brookings Institution conference.

Blomqvist, K. (2002). *Partnering in the Dynamic Environment: the Role of Trust in Asymmetric Technology Partnership Formation*. Retrieved from http://www.doria.fi/handle/10024/38551

Brinkerhoff, J. M. (2002). Assessing and improving partnership relationships and outcomes: A proposed framework. *Evaluation and Program Planning*, *25*(3), 215–231. doi:10.1016/S0149-7189(02)00017-4

Chesbrough, H. W. (2003 Spring Issue). The Era of Open Innovation. *MIT Sloan Management Review.* Retrieved from http://sloanreview.mit.edu/article/the-era-of-open-innovation/

Concilio, G., De Bonis, L., Marsh, J., & Trapani, F. (2011). Urban Smartness: Perspectives Arising in the Periphèria Project. *Journal of Knowledge Economy*, *4*(2), 205–216.

Concilio, G., Marsh, J., Molinari, F., & Rizzo, F. (2013). Human Smart Cities. A New Vision for Redesigning Urban Community and Citizen's Life. In *Proceedings of the 8th International Conference on Knowledge, Information and Creativity Support Systems*. Krakow, Poland.

Concilio, G., & Molinari, F. (2014). Urban Living Labs: Learning Environments for Collective Behavioural Change. *Proceedings of the IFKAD '14 Conference*. Matera, Italy.

Concilio, G., Molinari, F., & Puerari, E. (2014). Rethinking Activism: Living Labs and Urban Participation. Contribution presented at *the EURA 2014 Conference*. Paris, France.

Crosta, P. (2006). *Interazioni: pratiche, politiche e produzione di pubblico. Un percorso attraverso la letteratura, con attenzione al conflitto. DiAP WSs*. Milan: Politecnico di Milano.

De Reuveur, G. A. (2009). *Governing mobile service innovation in co-evolving value networks.* Retrieved from http://repository.tudelft.nl/view/ir/uuid:e9e31abe-440b-4440-a5bb-f6760251601f/

European Commission. (2014). *Guidance on Community-Led Local Development for Local Actors*. Retrieved from http://ec.europa.eu/regional_policy/sources/docgener/informat/2014/guidance_clld_local_actors.pdf

European Commission. (n.d.) *Leader Tool-Kit*. Retrieved from http://enrd.ec.europa.eu/enrd-static/leader/leader/leader-tool-kit/the-leader-approach/en/the-leader-approach_en.html

Hellström, R. M., McCormick, K., Nilsson, E., & Arsenault, N. (2012). Advancing Sustainable Urban Transformation through Living Labs: Looking to the Öresund Region. In *Proceedings of the International Conference on Sustainability Transitions*. Copenhagen, Denmark.

Hou, J. (Ed.). (2010). *Insurgent public space. Guerrilla urbanism and the remaking of contemporary cities*. Abingdon: Routledge.

Juujärvi, S., & Pesso, K. (2013). Actor Roles in an Urban Living Lab: What Can We Learn from Suurpelto, Finland? *Technology Innovation Management Review*. Retrieved from http://timreview.ca/article/742

Kaletka, C., Kopp, R., & Pelka, B. (2011). Social Media Revisited. User Generated Content as a Social Innovation for eInclusion. In *Proceedings of International AAAI Conference on Weblogs and Social Media*. Barcelona, Spain.

Molinari, F. (2011). Living Labs as Multi-Stakeholder Platforms for the eGovernance of Innovation. In *Proceedings of the ICEGOV11 Conference*. Tallin, Estonia. doi:10.1145/2072069.2072092

Moulaert, F. (2010). Social Innovation And Community Development: Concepts, Theories And Challenges. In F. Moulaert, E. Swyngedouw, F. Martinelli, & S. Gonzalez (Eds.), *Can Neighbourhood save the city? Community development and social innovation*. Abingdon: Routledge.

Moulgan, G. (2007). *Social innovation. What it is, why it matters and how it can be accelerated*. Oxford SAID Business School. Retrieved from http://eureka.bodleian.ox.ac.uk/761/1/Social_Innovation.pdf

Mulgan, G., & Albury, D. (2003). *Innovations in the Public Sector*. London: Cabinet Office.

Nam, D., & Pardo, T. A. (2011). Smart City as Urban Innovation: Focusing on Management, Policy, and Context. In *Proceedings of ICEGOV2011 Conference*. Tallinn, Estonia. doi:10.1145/2072069.2072100

Osimo, D., Zinnbauer, D., & Bianchi, A. (Eds.). (2007). *The future of eGovernment. An exploration of ICT-driven models of eGovernment for the EU in 2020*. European Commission, Joint Research Centre, Institute for Prospective Technological Studies. Retrieved from http://ftp.jrc.es/eur22897en.pdf

Pallot, M. (2009). *The Living Lab Approach: A User Centred Open Innovation Ecosystem. Webergence Blog*. Retrieved from http://www.cwe-projects.eu/pub/bscw.cgi1715404

Paskaleva, K. (2001). *Innovative partnerships effective governance of sustainable urban tourism*. Retrieved from http://sut.itas.fzk.de/papers/pack1/SUT_Deliverable1_FrameworkApproach.pdf

Periphèria. (2013). *Policy document*. Retrieved from http://www.peripheria.eu/library/peripheria-policy-document

Schuler, D. (2013). Innovating Democracies. Presentation given at the Smart Communities session of the Smart Cities Exhibition. Bologna, Italy.

SERCO Institute. (2012). *Frugal Innovation. Learning from Social Entrepreneurs in India*. Retrieved from http://www.serco.com/Images/FrugalInnovation_tcm3-39462.pdf

United Nations. (2008). *Guidebook on promoting good governance in public-private partnership*. Retrieved from http://www.unece.org/fileadmin/DAM/ceci/publications/ppp.pdf

Urban Europe, J. P. I. (2013). *Call for Proposals*. Retrieved from http://www.jpi-urbaneurope.eu/ds resource?objectid=329044&type=org

Verilhac, I., Pallot, M., & Aragall, F. (2012). IDeALL: Exploring the Way to Integrate Design for All within Living Labs. In *Proceedings of the 18th International Conference on Engineering, Technology and Innovation*. Munich, Germany. doi:10.1109/ICE.2012.6297699

Webb, M., Finighan, R., Buscher, V., Doody, L., Cosgrave, E., Giles, S., . . . Mulligan, C. (2011). *Information marketplaces, the new economics of cities*. Report from The Climate Group, Arup, Accenture and Horizon, University of Nottingham. Retrieved from http://www.theclimategroup.org/what-we-do/publications/Information-Marketplaces-The-New-Economics-of-Cities/

World Bank. (2015). *Community-driven development overview*. Retrieved from http://www.worldbank.org/en/topic/communitydrivendevelopment/overview

KEY TERMS AND DEFINITIONS

Living Labs: Are user-driven, open-innovation ecosystems operating in real-life environments and framed within public-private-people partnerships.

Public Private Partnership (PPP): Is a formal or informal alliance between government and private sector bodies for the provision of public services to citizens or businesses.

Public Private People Partnership: Is a PPP integrated by the active contribution of people, either through co-design or co-production of services, or both.

Service Co-Design: Is a service design process instantiation where service beneficiaries actively cooperate with service designers bringing their first hand experiences, ideas and expectations.

Urban Innovation Governance: Is a set of principles, methods and practices aimed at the management of innovation epiphanies in multi-stakeholder (like urban or periurban) settings.

Urban Living Labs: Are Living Lab settings for socio-digital innovation in City or Neighbourhood contexts.

Section 3

Smart Cities at the Crossroad among Energy, Mobility and ICT

Chapter 7
Multi-Scale, Multi-Dimensional Modelling of Future Energy Systems

Catalina Spataru
UCL Energy Institute, UK

Andreas Koch
EIFER European Institute for Energy Research, Germany

Pierrick Bouffaron
EIFER European Institute for Energy Research, Germany

ABSTRACT

This chapter provides a discussion of current multi-scale energy systems expressed by a multitude of data and simulation models, and how these modelling approaches can be (re)designed or combined to improve the representation of such system. It aims to address the knowledge gap in energy system modelling in order to better understand its existing and future challenges. The frontiers between operational algorithms embedded in hardware and modelling control strategies are becoming fuzzier: therefore the paradigm of modelling intelligent urban energy systems for the future has to be constantly evolving. The chapter concludes on the need to build a holistic, multi-dimensional and multi-scale framework in order to address tomorrow's urban energy challenges. Advances in multi-scale methods applied to material science, chemistry, fluid dynamics, and biology have not been transferred to the full extend to power system engineering. New tools are therefore necessary to describe dynamics of coupled energy systems with optimal control.

BACKGROUND

Many countries around the world still rely heavily on conventional fossil and nuclear energy. Targets are now being set around the world to reduce greenhouse gas emissions (European Commission, 2014). Most carbon reduction scenarios rely on a combination of decarbonised supply and demand reduction to achieve the medium to long-term targets (GEA, 2012). In recent years, significant efforts worldwide at multiple layers, from individual energy systems to whole energy systems,

DOI: 10.4018/978-1-4666-8282-5.ch007

and at different levels, from research to policy analysis, have been undertaken to analyse the integration of renewables into the system. Furthermore, inter-governmental and non-governmental institutions have proposed various scenarios to support energy policy makers. Table 1 provides a list with worldwide scenario studies carried out by a number of institutions covering a broad range of stakeholder groups and published recently in 2012-2013. Each scenario has diverse results in terms of energy use, technological efficiency and the energy resources mix, all having as a main goal to succeed global energy access, especially for developing countries, to reduce air pollution and tackle climate change while improving energy security worldwide.

To generate scenarios, energy models have been used. Since the early 1970s, a wide range of models to analyse energy systems and sub-systems have become available worldwide. Various approaches and tools are used: agent-based models; Geographic Information Systems (GIS) or system dynamics to name just a few. However, today, many energy system models are still based on linear approaches while system interaction is known to be the key. In addition, many engineering tools do not allow a thorough spatial definition of the systems. Granular 3D GIS data and GIS technology can add significant value to the modelling of energy systems. This is important because the multiple interacting systems in the urban context are not only connected through their spatial proximity but also through functional units (called virtual power plants).

By coupling dynamic models with GIS which allow for spatial analysis, data interpretation makes it possible to develop more coherent models that are both dynamic and spatially explicit. These advantages are widely discussed in literature. Jebaraj and Iniyan (2006) provide a detailed overview of a large range of energy models: supply-demand models, forecasting models, optimization models, neural-network models and emissions models covering 252 publications. Keirstead et al. (2012) provide an overview of urban energy system models covering 219 publications.

The different existing modelling techniques have various strengths, weaknesses, capabilities and applicability. By quantifying and predicting consumption patterns due to retrofits or technology evolution, they can act as technology incentives (Huang & Broderick, 2000; Aydinalp et al., 2002; Kadian et. al., 2007).

Energy models are applied to specific scales – a building, a district, a city or even a state. The detail needed for the interface is a combination of data availability, model purpose and assumptions. A detailed model allows for deeper analysis of end-use consumers and particulars. Accurate assumptions can make the modelling process easier and still provide reliable results. However, the accuracy of the results relies on input data and on the availability of information.

Some models have attempted to predict how energy flows might change over time (Summerfield et al., 2010). Significant advances have been seen in energy demand predictions for buildings (residential, commercial, industrial) as distinct categories and to estimate energy demand. In addition, significant efforts have looked at the energy supply side, where various models can be used to interrogate the evolution of renewables with GIS technologies.

Recently, the major trend has been to develop integrated and holistic models of the systems. Models can be classified in different ways, on different temporal and spatial dimensions, by application focus and simulation approach.

There are data-driven models such as MARKAL family models (Faraji-Zonooz et al., 2009) which represent the evolution over a period of usually 40-50 years of a specific energy system at national, regional or community level.

In addition to the aforementioned models, other types of energy models exist: econometric models which combine economic theory and statistical

Table 1. Selected reports on worldwide energy scenarios by inter-governmental and non-governmental institutions as well as industry

Study	Link	Scenarios	Projection Time
Inter-Governmental Institutions			
Global Energy Assessment, by IIASA 2012	http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/Global-Energy-Assessment-Database.en.htm	Supply, Efficiency, Mix	2050
Energy Technology Perspectives, by IEA 2012	-	6DS, 2DS, 4DS	2050
Industry			
New Lens Scenarios, by Shell 2013	http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/O/2012_2030_energy_outlook_booklet.pdf	Mountains, Oceans	2060
BP Energy Outlook, by BP 2012	http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/O/2012_2030_energy_outlook_booklet.pdf	-	2030
The Outlook For Energy: a view to 2040, by ExxonMobil 2013	http://www.exxonmobil.co.uk/Corporate/files/news_pub_eo.pdf	-	2040
Energy Perspectives, by Statoil 2012	http://www.statoil.com/en/NewsAndMedia/News/Downloads/Energy%20Perspectives%202012.pdf	Base Case (2 alternatives: Globalised expansion, Regionalised stagnation)	
Global Renewable Energy Market Outlook, by Bloomberg New Energy Finance 2013	http://about.bnef.com/files/2013/04/Global-Renewable-Energy-Market-Outlook-2013.pdf	Traditional Territory, New Normal, Barrier Bursting	2030
Non-Governmental Organisations			
Energy [R]evolution by Greenpeace, & EREC 2013	http://www.greenpeace.nl/Global/nederland/report/2013/klimaat%20en%20energie/energy-revolution-scenario.pdf	Reference, Energy Revolution	2050
2050 Global Energy Scenarios, by WEC 2013	-	Jazz, Symphony	2050

techniques; statistical and artificial intelligence models; neural networks or fuzzy logic models.

Energy models are used for a large variety of reasons and goals – for instance the determination of national or local energy requirements, but most of the time to guide energy policy decisions regarding, for example, residential stock. One of the main goals of energy modelling is to create tools for the analysis of energy systems to e.g. support investment decisions in energy planning and policy making. On the different scales and levels of detail described above, energy models represent the physical energy systems. Depending on the chosen modelling approach it can be described in a more or less abstract form in the case of statistic energy system models or include detailed physical properties as well as complex relations between system parameters.

Energy modelling has been and still is the fundamental approach for energy planners. Basic approaches still used and valid today were developed as far back as fifty years ago (Rath-Nagel & Voss, 1981; Catrinu, 2006) as a response to severe energy problems. While early energy models focused mainly on demand patterns supplied by a single energy carrier, such as electricity, oil or natural gas, current and future energy systems have become more interconnected. Related to different actors in the different energy markets, the common challenges in the operation of today's energy systems are related to changes in energy prices, technological development and environment conditions. Not least, such questions emerge from the need to integrate a higher share of renewable energy in the energy system using the existing infrastructure.

Despite the diversity of the modelling approaches shown above, many challenges are similar: spatial variables, specific data intensity, availability and credibility of data, policy relevance and integrated multi-layer structures. Depending on the project and the selected methodology, the availability of the data may be the major challenge. It can range from the physical characteristics of buildings and networks to the historical energy consumption of other projects, local economic and macro-economic indicators, and climate data. Whenever the information is collected independently or concurrently, the obtained raw data may strongly vary in level of detail. Basic collections are generally surveys, but they could also be available public studies or analyses from energy providers.

A WAY FORWARD

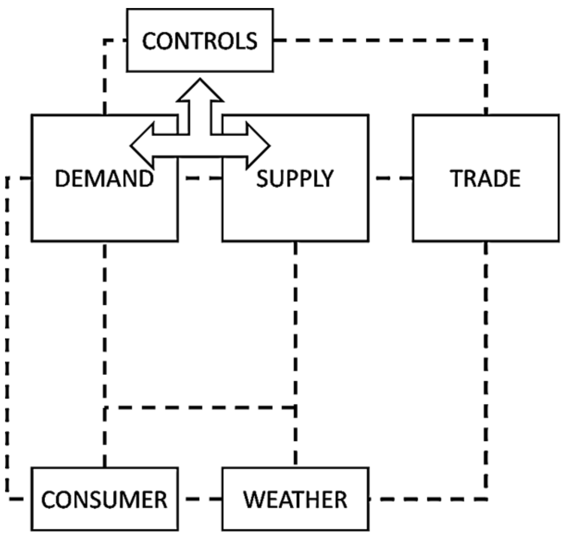
The ability of academia to rise to the challenge has long been limited by historic methodological and interdisciplinary fragmentation. The recent acknowledgement that interdisciplinary approaches are a necessity stems from the fact that complexity arises in many disciplines. Complex behaviours span a wide range of epistemological levels. On one hand, in the case of energy systems at the district scale, complexity comes in particular from the interaction between buildings, people and their use of technologies. On the other hand, in the case of energy performance in dwellings, the complex behaviour comes from the interaction of different sub-systems from the physics of heat transfer, through the physiology and psychology of occupant behaviour to the socio-economics of the building industry. In both examples and at large, mono-disciplinary attempts to understand such behaviours run the risk of underestimating or entirely neglecting effects that arise outside the core discipline.

There is little doubt that the energy sector is complex in its core, as is its representation. Energy systems are dissipative systems, which evolve over time, with significant qualitative, quantitative and structural change which can take place over decades. They are characterized by non-linearity, time lags, feedback, high levels of topological complexity, and sometimes chaotic behaviour.

Energy systems are also fractal and hierarchical: as a result, the computational demands of modelling are dominated by the combinatory explosion of categories. Significant strands of modelling are still constrained today by the computing resources available – this is the case with the highly innovative demand-supply system modelling (Figure 1).

Current energy systems are also evolving both in scale and in complexity through the addition of

Figure 1. Energy system model main components diagram
(Spataru & Barrett, 2012)



levels of interconnection (e.g. interlinking electricity and gas distributions systems), the growing addition of large tranches of renewable energy production, the use of storage at local and central level and the development of demand response and dynamic pricing. This evolution implies a move from static resistive-inductive networks with one-way flows of energy and communication between levels, to systems involving two-way communication and flows, with embedded intelligence at all levels (IEA, 2011). In addition, a closer coupling is necessary between existing energy infrastructures and end uses: gas and electricity systems as a result of the use of gas for electricity generation, heat and electricity production through the development of combined heat and power and district heating systems and the likelihood that electricity will assume a strategic role in transport, control as well as fixed end-uses (IEA, 2014).

To understand and manage such energy systems, a trans-disciplinary approach involving multiple technical and non-technical domains is required. First, the spatial and temporal information between demand and supply, along with energy storage options playing the role of buffer and common control algorithms is to be considered in a unified way. Also, a fully-integrated approach is a prerequisite to understand and assess energy systems at every scale: from buildings through neighbourhoods towards cities. To reach this ambitious goal, information is key. The communication needs in the management of future smart energy systems are going to shift the system view towards cyber-physical systems in which communication and infrastructure will have to be modelled at the same time. In addition, the energy system models must incorporate multiple sectors not least to explore load management potentials. Broader and comprehensive model frameworks are necessary to understand the technical and economic impacts of adopting new energy policies and technologies. Understanding every aspect of energy and climate issues is essential in the 21st century challenges of decarbonisation, energy security and cost-effectiveness to help assist energy policy makers and industrial stakeholders to assess future energy systems and make realistic future proof technical and economic decisions.

All these integrated applications spanning a certain number of sectors, energy carriers, technologies, etc. will require a great effort in the harmonization of the system description or at least interfaces between system boundaries and different scales. In addition to the possibility of the ad hoc coupling of systems, standardization seems the logical sustainable path to enable cross-system communication of any sort.

The next sections will discuss three main additional components for future energy systems and grid models: cyber-physical systems, distributed energy generation and the integration of multiple dimensions.

ADDITIONAL COMPONENTS FOR FUTURE ENERGY SYSTEMS AND GRID MODELS

Cyber-Physical Systems

Society and energy systems are one interconnected system in which each part affects all others, albeit indirectly. The dynamics of human and technology systems, especially with high levels on uncontrollable renewable supply, critically determine the optimal sizing of system components and their control. The peaks imposed on energy networks will depend on many factors including control, diversity, storage, multi-fuelling and the renewable supply mix. It can be assumed that the future energy system will neither be a centralized nor a completely decentralized system but based on interconnected distributed systems. This also implies that communication will take place on the corresponding aggregation scales.

Cyber-physical systems are basically integrations of computation, networking, and physical processes, referring to the next generation embedded Information and Communication Technologies (ICT) that are interconnected and collaborating through the internet of things. They integrate the dynamics of the physical processes with those of the software and networking, and are expected to provide society with a new range of applications and services. The ICT systems are expected to make modern transport systems, domestic buildings, service and industrial buildings smarter and more energy efficient.

With regards to energy networks, cyber-physical systems put forward the question on which scale the intelligence of the system must be hosted. Alanne and Saari (2006) propose, for example, to make a clear distinction between centralised, distributed and decentralised systems. The latter can be seen as individual systems on a small scale that do not follow a common strategy while the former implies specific levels of central and local intelligence interacting with each other.

Distributed Energy Systems

The transition towards future smart grids calls for an integrated energy management solution: matching supply and demand patterns with growing shares of renewable generation while minimizing storage and transmission capacities, and ensuring the resilience of the entire system. Tomorrow's electricity grid design is driven by the growing availability of distributed generation resources that provide both challenges and opportunities.

The challenges of distributed systems are numerous. For example many countries have already experienced situations when wind power production is high during low electricity demand. To ensure frequency standards, system operators generally manage supply and demand using interconnections with adjacent regions (Soder et al., 2007), but they might be forced to curtail wind power: this is then a loss of "free" energy. Storage can be the key, but matching production and demand with storage implies the development of energy logistics to ensure energy is available when and where needed and not excessively overprovisioned. The optimization of energy consumption in computing and communication systems involves manufacturing energy proportional devices or developing energy aware algorithms for scheduling and routing.

However, decentralised systems also have several advantages. Some of these are: avoiding network losses, reducing transmission and distribution costs, requiring less backup capacity due to the fact that many small generators are less likely to suffer a major impact from the outage of a single generator (Spataru, 2013). One of the main benefits is that distributed generation can be tailored to local conditions and installed much faster than a centralised system. With distributed generation and storage, energy consumers become producers of electricity. The social involvement in energy preservation and production, by providing incentives and increasing the population's awareness of its benefits is a very important aspect.

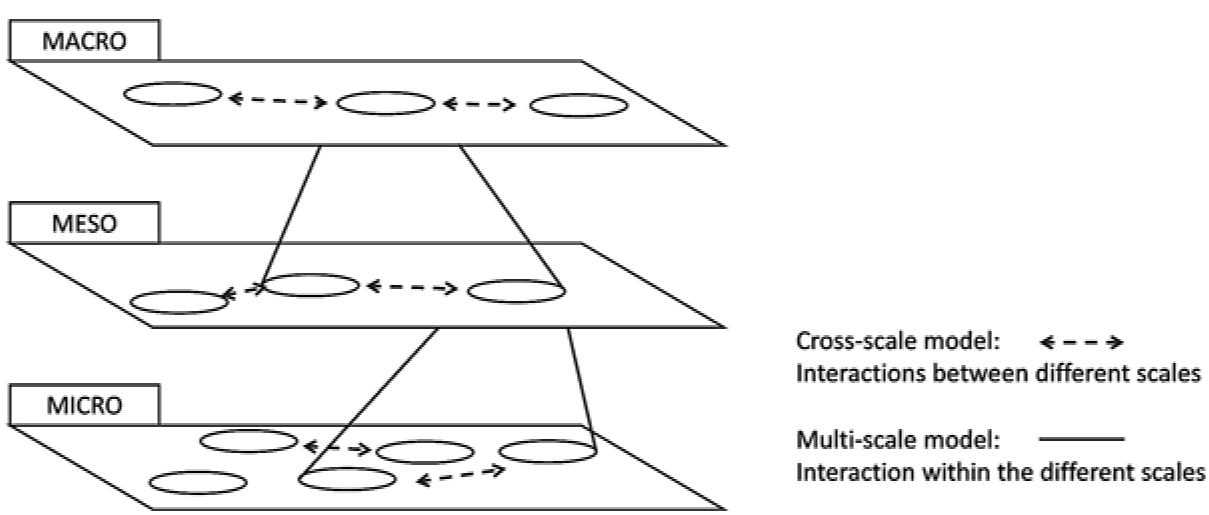
Decentralisation has already started to take place quite significantly with widespread integration in the European energy market, especially in Denmark, the Netherlands, Sweden, Germany and Spain (Spataru, 2013). However, there is still major investment in centralised energy production technologies. This happens especially due to the structure of the European electricity and gas markets and concomitant regulations, but also due to the fact that existing structures support centralised energy systems.

Multiple Systems Integration

As today's urban energy systems become more and more interconnected, they can be seen as complex systems, or systems-of-systems, with a large number of heterogeneous entities. The interaction between various different connected layers of energy systems emerges from a multitude of dimensions: physical/technical (the hardware of the network), market and business (wholesale and retail, services and operations), social (customers, users, stakeholders), normative (administrative issues, standards etc.), political (local, national, regional decision-making and geopolitical implications), cyber (measurement, communication and control). The interactions between the different layers exhibit the complexity mentioned above. The coupling of the various layers needs to be studied to identify the benefits of interconnections in space and time. For example, in power systems there is an interconnected sub-systems relation between the wide transmission system and neighbourhood distribution networks. Another case is the interaction between climate conditions and energy consumption in buildings through the operation of technologies. The integration of modelling at different dimensions (micro, meso and macro), from the financial side to find the most economic transition path, to technical and social, is becoming a necessity (Figure 2).

The multi-scale modelling of energy resources, technologies, policies and control systems is crucial to understanding the dynamics of energy and society. Different approaches have been assessed, sometimes combined, ranging from traditional bottom-up representations including statistical and physical methods to top-down approaches treating the district areas as an energy sink and not detailing individual end-uses (Koch et al., 2003). Each method shows strengths and limits,

Figure 2. Interactions within different scales and levels
(Kremers, 2013)



relying on various levels of inputs, different modelling philosophies, and leading to a large range of applicable results. The multi-scale modelling of energy resources, technologies, policies and control systems is to be thoroughly detailed and integrated into a necessary process of information analysis.

There are several sub-areas where more improvements in the research are needed, in particular regarding the modelling linkage between different technical systems, society and the economy. From the energy performance of buildings to the technical definition of energy networks, every stage of the modelling process has an impact on the whole project value chain. One of the challenges is to determine the behaviour of different sub-systems, their characteristics and interactions and how this understanding will remain relevant in the future. Another one is to develop strategies for the efficient operation of coupled systems; the integration of distributed storage, the diversification of energy services and changing the role of actors in energy markets.

LOCATION, TIME, AND SPATIAL SCALE

The deployment of integrated energy solutions varies with location, spatial scale and technical design choices. It is also strongly dependent on the existing infrastructure and its resilience to supply and demand variability, as well as on current practices and regulations.

Spatial Scale

In the development of integrated models, one of the major challenges is the interaction and dynamics between different spatial scales and capturing these dynamics at macro and micro levels. Many current integrated models are constrained to one spatial scale such as a building, neighbourhood, district or city. In reality, energy consumption depends on different variables at different spatial scales which need to be taken into account when optimising the urban energy infrastructure. In current practice, energy system representation typically focuses on a main scale and depicts macro phenomena in the form of exogenous assumptions. For example, scale is in many ways a prerequisite often inherently assumed for the prediction of energy use over time. Hourly load curves vary greatly depending on the scale of the assessment yet above a certain number of users, the systems can be expected to behave similarly but without showing a strong smoothing effect by further enlargement of the system boundary. When modelling systemic interactions, this approach falls short of delivering a dynamic system model. Considering in space and at fine time resolution, the number and the type of selected components to be connected have great technical, financial and environmental impacts due to the sizing of infrastructure, the choices, technologies and the necessity of operating the whole system. A further advantage of lager scales results also from distributional effects of different components, with systemic influences from independent or stochastic influences, suitable for reducing the insecurity inherent in the energy assessment.

Location

A technology that has been implemented successfully in one region may not enjoy the same success in another region. Due to the uneven distribution of natural resource deposits across large areas, the pattern of the use of resources is quite different from one region to another. Increasing pressures on vital natural resources due to climate change and population growth necessitate a paradigm shift in the way we perceive sustainable development and manage resources. The resource nexus (which includes energy but also water) sits at the intersection of many critical economic, political and social issues. The complex and interwoven connection issues require analysis and policy approaches that explicitly recognize these connections. Depending on the specifics of a given energy system in a specific location, a portfolio of solutions to minimize the risks to the system and the costs can include the development of centralized versus distributed generation (or both), as well as a strong extension of the network infrastructure versus more off-grid alternatives.

Time Scale

Energy demand varies temporally according to social activity patterns (home, work, travel), demand management (insulation levels, space heating requirements, lighting, cooling) and weather (ambient temperature, wind, solar radiation). Energy demand thus varies throughout the year and on a sub-hourly basis. The entailed variability of demand impacts the technical and economical requirements on the energy supply side, which today relies on larger shares of renewable (also variable!) as well as storage, back-up capacity and energy trade as buffers. The whole service supply system (as shown below), from people through end use technologies, is to be considered in order to comply with security and safety requirements, as well as the usability and adaptability of the entire system. In terms of modelling and simulation, this means favouring the use of systems-of-systems to multiply the decentralized decision processes, adopting a large number of heterogeneous entities and improving the communication and interactions between them.

BUILDING BLOCKS FOR A UNIFIED DESCRIPTION FOR ENERGY SYSTEM MODELS

We need to move from the classical approaches to multi-disciplinary approaches. For example, in demand-side management production currently follows demand, but in the modern electricity system demand side management needs to adopt a more dynamic approach, making it possible to improve energy efficiency, to reduce peak loads and shift loads over time, increase valley loads and stabilize grid frequency.

The temporal profiles over periods of minutes or hours of demand and supply critically determine the peak capacities of networks. Any mismatch between instantaneous demand and supply in a segment of the (gas, electricity, heat) network, has to be met with storage, dispatchable energy supplies and transmission or manageable demand or services. With multiple handles for optimization and aggregation scales on different system levels, this requires a complex control strategy that accounts for all demands and supplies into the network but does not necessarily result in minimized peak network flows.

MULTI-SCALE ENERGY SYSTEM USE CASES

Example 1: Micro-Simulation of Household Appliances

In the MILLENER project the micro-simulation of household appliances analysed at different network layers of the electrical grid is another example of a multi-scale energy system model that integrates different spatial as well as temporal scales. In order to investigate the system-wide effects of different demand side management strategies, more than 100,000 buildings were represented in the agent-based simulation framework TAFAT (Kremers et al., 2012). Historic consumption data was disaggregated from the higher grid levels and referenced to the geo-localised household representations. Each household was equipped with a number of appliances which could individually be operated according to the tested smart grid strategies. Based on the selected set of measures, the individual load curves were modulated and re-aggregated to represent higher grid levels (Figure 3). In order to evaluate the system-wide effects, the topology of the network was included in the model. A mayor challenge of the model development was not only posed by the management of the multitude of objects but even more so by the multiple temporal scales: while frequency events had to be represented in timeframes of seconds, the integration of renewables is usually investigated at daily or higher timescales when regarding future scenarios. In parallel, the results from the modelling were reported both at the scale of the transmission or distribution grid down to individual substations or households to validate and discuss the simulation results.

Example 2: Monthly Balanced for Net-Zero Energy Buildings

In the case of net-zero energy buildings, the indicator defined at European level in the Energy Performance of Building Directive relates to an annual time scale. Figure 4 shows the monthly balance for a net-zero energy building. The load match index is defined as the share of demand satisfied by the supply. With a monthly resolution the load match index reaches a level of approximately 65%. In the same technical system the load match decreases to 25% when described with an hourly resolution (Koch et al., 2012).

In the concept of net-zero buildings two systems are coupled in the balance, which have very different scopes. The thermal needs of building

Figure 3. Disaggregation of historic consumption data and reaggregation to higher voltage levels after modification at household level
(Kremers et al., 2012)

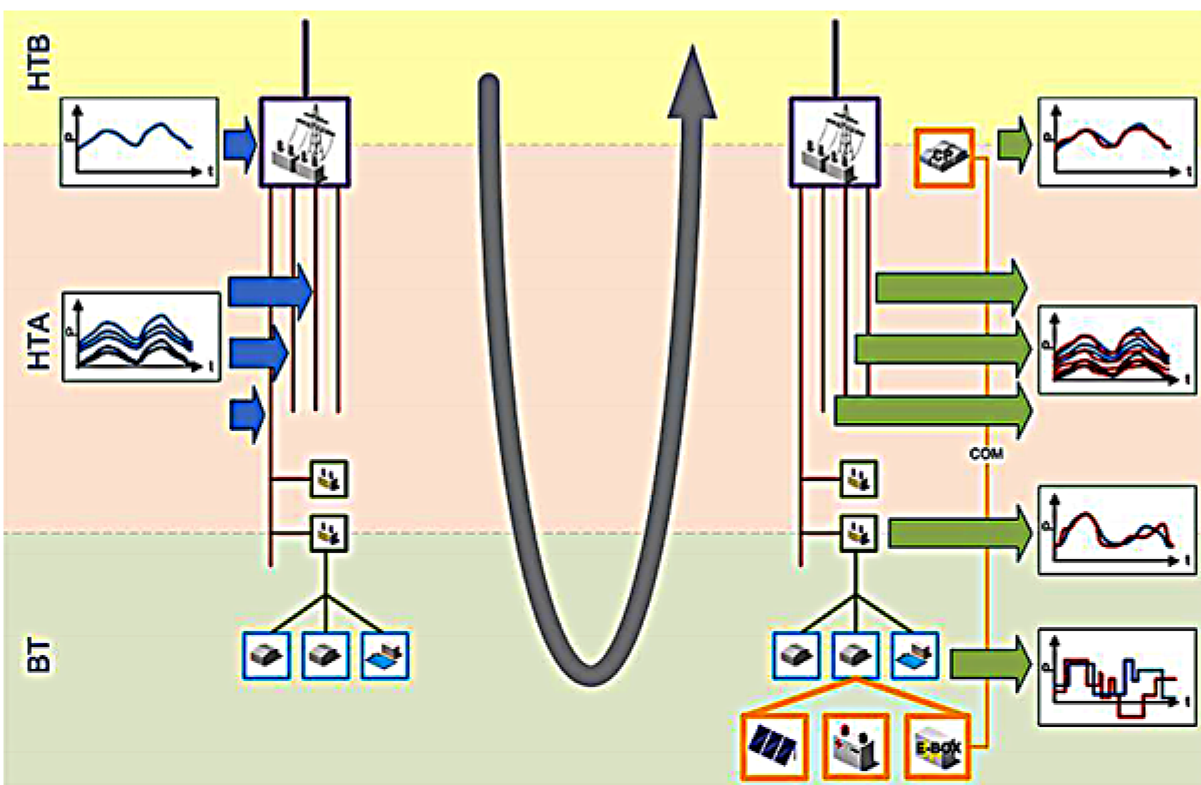
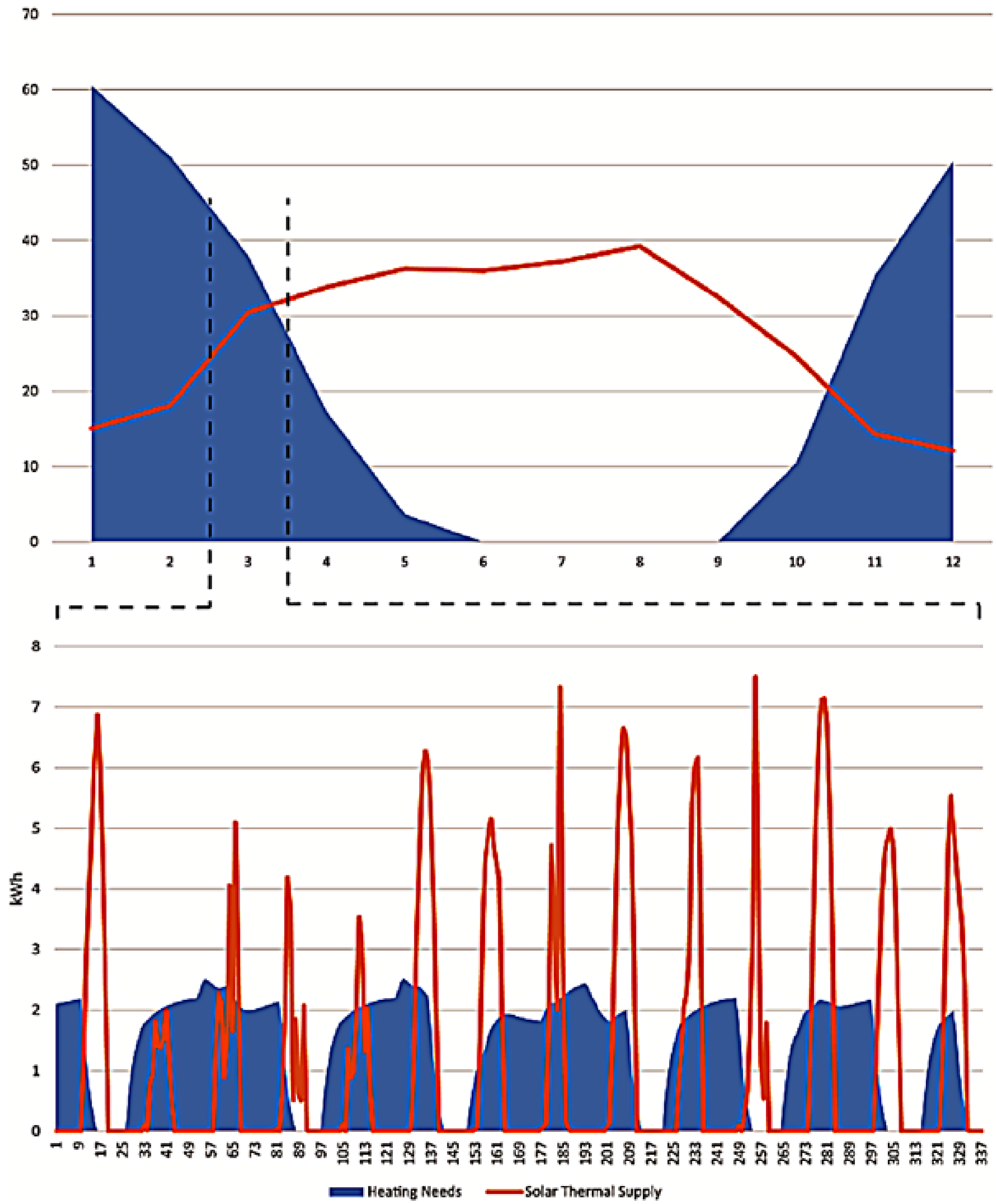


Figure 4. Monthly and hourly energy demand (Q) and available solar thermal energy supply (Sol) for a net zero energy building after
(Koch et al., 2012)



systems are typically seen as local phenomena with little implication for higher system levels. Only district heating or cooling networks which historically were designed as uni-directional systems allow for a limited amount of interaction between buildings. When thermal needs are matched by local distributed generation technologies this local system starts interacting with the national electricity grid by feeding in electricity based on the availability of local renewables and the so-far isolated energy needs of the building. While net-zero buildings can be seen in this way as another component of a smart energy system, a holistic representation will require not only inter-sectorial models but a multi-scale modelling approach to better understand the possibly dynamic feedback of the different systems.

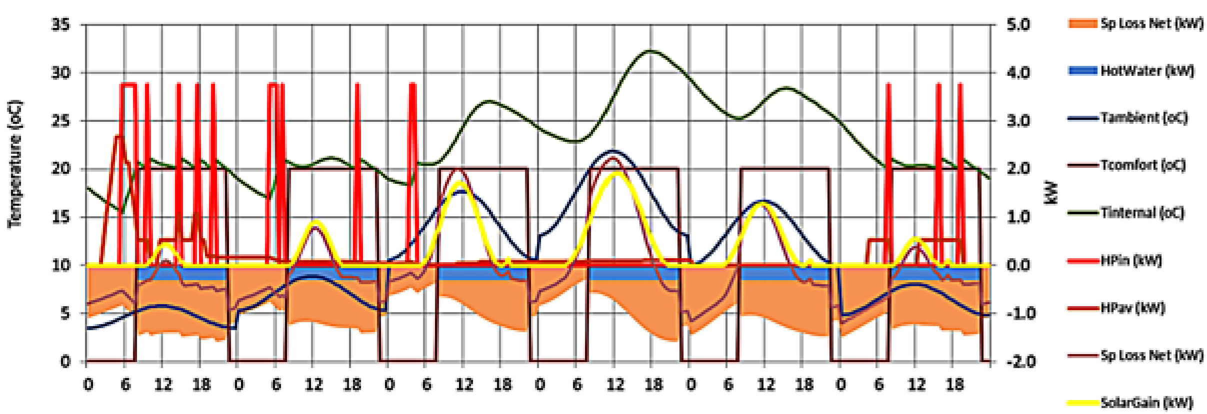
Example 3: Optimization of Building Energy Systems and Controls

Figure 5 shows an example of optimizing building energy systems and controls. Given a set of decision variables, Barrett and Spataru (2013) determined the building energy efficiency, heating system and heating controls (on/off timing). This highlighted design tensions: heat storage can be increased by raising the maximum storage temperature, but then the heat pump coefficient of performance is reduced; or by increasing storage volume but space is limited. The heat pump coefficient of performance might be increased by the direct supply of heat to emitters, rather than through a heat store, but then would be less storage.

The main challenges are to simulate the real time operation of systems with temporally varying demands driven by activities and weather, and to ensure the reliable delivery of energy services across hours, days and months.

According to Barrett and Spataru (2013), optimization should be carried out across all systems and stock, and simultaneously for configuration, size and controls so as to find a combination of system components (building efficiency, energy conversion, storage) and operational control that will deliver the lowest cost given a delivered energy cost whilst meeting objectives such as energy services and constraints such as carbon emission.

Figure 5. Optimizing building energy systems and storage for 6 sample days: 1 day/month (from left to right): Months 1,3,5,7,9,11
(Barrett & Spataru, 2013)



ADVANCED MODELLING APPROACHES FOR COMPLEX ENERGY SYSTEMS

The applied case studies cited above cannot claim to deliver the full picture but are used to convey a part of a possible solution.

Several challenges stem from the integration of renewable resources into future energy systems. Most renewable resources are location specific. Some renewable sources lack the flexibility needed to deal with certain aspects of power system operation, due to their variability across and predictability. The variability vs. predictability of various non-dispatchable generating resources differs from one to another. Wind and solar are more volatile and uncertain sources, while biomass and geothermal more stable and better known sources.

Balancing demand and supply is generally done by the control of generation, automatically or by a central electricity system operator, who monitors and operates the equipment in the transmission system and in power generating stations.

Due to the high variability as seen above, planning is critical because it takes generation time from instruction to generation as follow:

- Nuclear – 48 hrs
- Coal Fired – 12 hrs
- Oil Fired – 8hrs
- CCGT – 6 hrs
- Gas turbines – 2min
- Hydro – 20s
- Wind – N/A

Furthermore, the temporal scale of the chosen system representation has to respond to the given question to answer reflecting the physics and the different levels of uncertainty of the real technologies.

Over time periods longer than 30 minutes but less than 24 hours, decisions must be made in terms of which power stations should be turned on/off or ramped up/ramped down to ensure demand is met at any time during the day. The operators usually do this by using the unit commitment method (Wood & Wollenberg, 2012), which consists of complex optimizations that are conducted, typically one to two days ahead, to create a half-hourly schedule of generators required to reliably meet the forecasted demand at the lowest cost. The running time of the unit depends on its operation cost, the fuel used and efficiency, and the speed with which it changes its output power.

The requirements to answer as regards the many emerging new topics related to the way we are using energy resources, as discussed in greater detail, above can only be translated into some first high level requirements in this context.

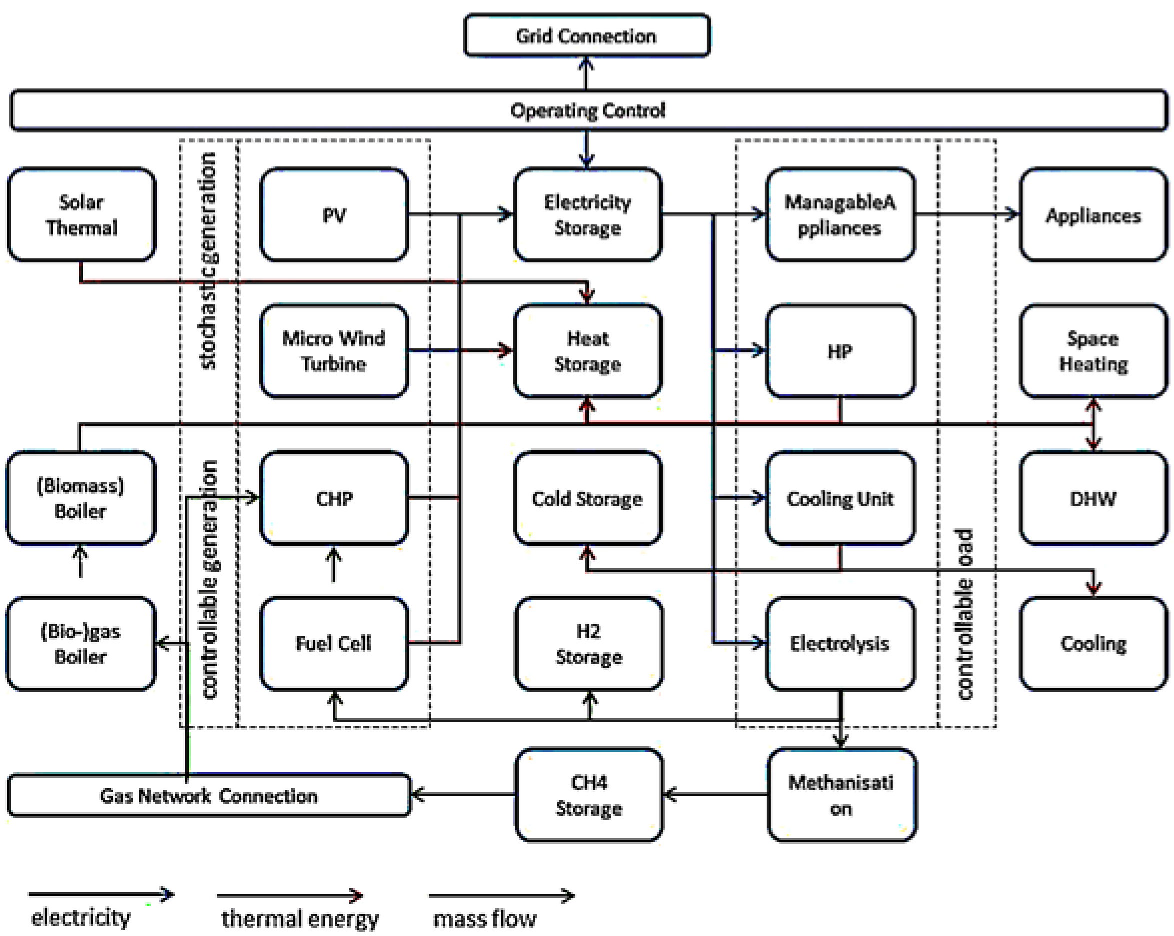
Example 1: An Integrated Multi-Scale Energy System of an Electric Island System

It has been shown that changes are also induced by the structure of the energy market and its characterization as a system of systems implies the use of new methods. In the context of smart grid demonstration projects Kremers et al. (2012) applied a complex system approach to the electric system of an island system. Here over 120,000 individual households were represented with a possible distribution of smart grid applications (see above). While at the scale of households the model can be regarded as an aggregation of different appliances (Evora et al., 2011), it provides a high level of detail at the whole system scale. The description as a system of systems is not new in the field of electrical energy systems and the different layers and connection points. However, as a generic approach was used in the form of a Java-based modelling language, the methodology is transferable to other sectors and could in theory be used to operate the physical hardware of subsystems as individual cyber-physical systems.

As an additional asset to the modelling paradigm, the monitoring aspect is to be integrated into the general project structure: multi-usage experiments and improved monitoring approaches will generate the production of large amounts of data and therefore improve post-analysis processes. Multiple experiences will then help engineers and planners to find the best possible balance between the necessary amounts of measured data versus the budget to invest in the monitoring phase.

Figure 6 shows a schematic representation of a hybrid energy system; in this generic example the scale is not considered. The main elements shown are, on the one hand, stochastic and controllable local electricity generation objects, as well as heating systems. The different conversion systems induce different interconnections to other systems which are indicated by a mass flow and output in the form of power and possibly heat. The local generation capacity is potentially coupled to the power grid and district heating network as well as local storage units. On the other hand, services such as space heating or the use of an appliance is enabled by local generation or transfer from another system. With regard to the demand side management potential the services are more or less controllable, i.e. can be shifted in time. This is often the case when connected to a storage unit as an additional system component.

Figure 6. Illustration of possible building blocks of an integrated multi-scale energy system *(Bahu et al., 2013)*



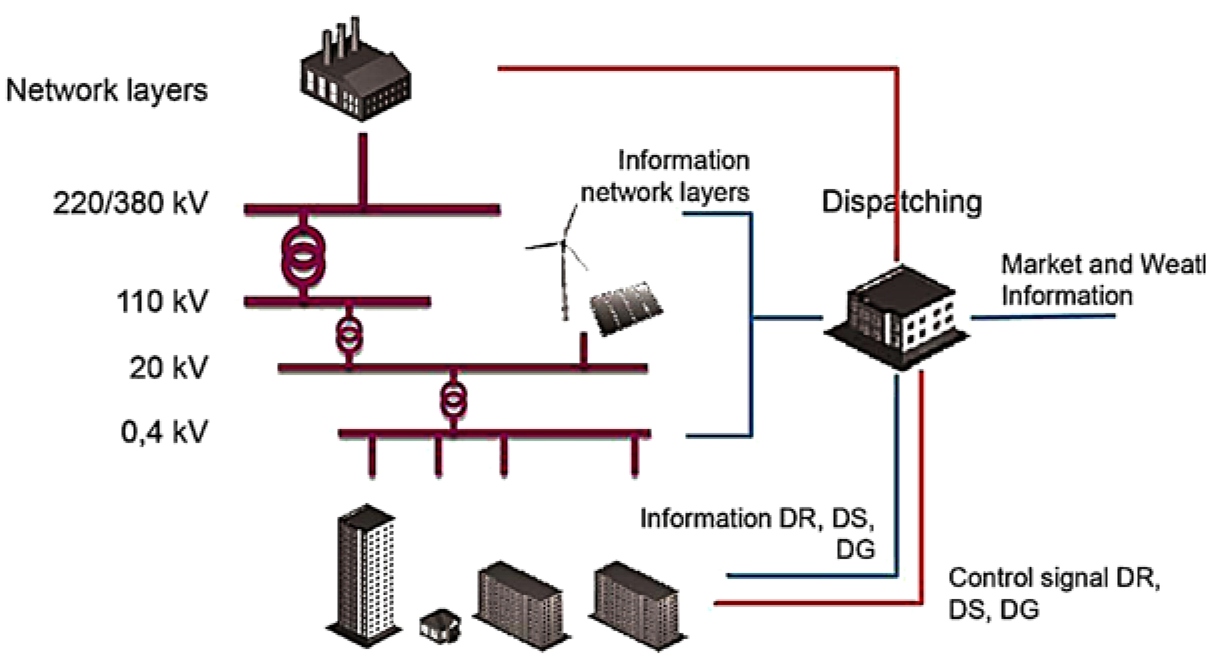
A further interconnection not included in the figure is often described by an additional link to the gas grid via power to gas technologies, which can be considered a further storage option (Nitsch et al., 2010).

Example 2: Hybrid Energy Systems at Lower System Levels

While in principle a wide range of different connections are possible, in practice systems tend to use as few components as possible as the interaction does not only increase flexibility but also complexity in operation and maintenance. Even though the full scope of objects might rarely be implemented in one single location, highly integrated hybrid systems could be virtually or physically coupled local systems that then interact on the next higher hierarchical level. Examples of such complex systems could be part of a local or national energy system at any scale and thus interact with other more or less developed hybrid systems. Figure 7.

From these integrated multi-energy or hybrid energy system configurations a number of specific requirements for the model development arise. Under the assumption that the individual components can be operated independently, it follows that intelligent coordination is necessary when system wide objectives are pursued. While it is a necessary prerequisite that a system component provides this service in the system, it could be located at different system levels, i.e. central or distributed control strategies are possible and not exclusive solutions for the operation. From this it follows that the hardware and thus their representations must be capable of communicating with each other, in the case of distributed intelligence a two-way communication between systems would be required. This would enable the measurement

Figure 7. Implementation of hybrid energy systems at lower system levels, distributed generation (DG), distributed energy storages (DS) and demand response (DR))
(Own illustration after (Wiechmann, 2008)



and processing of local data such as energy use, weather data, scheduling, operation status, etc. Only by these means a system wide optimisation of energy needs and on-site (fluctuating) generation can be achieved. Finally, such an intelligent energy system or its representation in the form of a model would provide the means of interacting with non-technical systems such as the electricity market via tariff systems or dynamic pricing mechanisms.

The described sketch of a system of systems can be seen as a use-case independent pattern which finds its equivalent in modelling energy systems for analytical purposes or in order to develop possible future scenarios to support investment decisions. As a second group of applications, the model-based optimization of a real system can be identified (Eicker, 2006). In future complex hybrid systems this might necessitate the use of detailed models for fault detection which could become less evident with a larger number of interdependencies between individual system components. Finally, the operations of individual hardware components within a model based assessment or the substitution of physical hardware with a virtual representation in cyber-physical systems represent possible future applications.

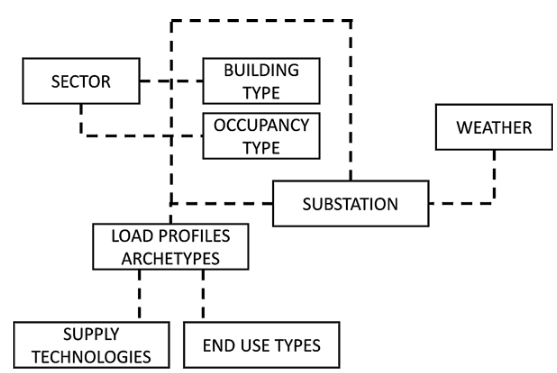
When modelling systems of systems, such as hybrid or interconnected energy systems, one common obstacle is the choice of a harmonious ontology (van Dam & Keirstead, 2010). On the scale of cities this need is also expressed in current efforts to develop common standards. The International Standards Organisation (ISO) created the ISO/TC 268268 "sustainable development in communities" committee in 2012. The technical committee (TC) includes two working groups that look at the management system and global city indicators. Furthermore, ISO created the subcommittee on smart community infrastructures. At European level, the standardisation bodies of different member states, such as AFNOR in France or DKE in cooperation with DIN in Germany, recently started a discussion on standard development. The latter recently released the first concept of the national smart city standardization roadmap (VDE 2014). At European level, CEN, CENELEC and ETSI created the "Smart and sustainable cities and communities" - Coordination Group (SSCC-CG).

Example 3: A Scalable Dynamic Energy Model for Regional Demand and Supply

To estimate and project total demands on a particular substation it is necessary to consider all connected loads (and generation) in the domestic and non-domestic sectors. A scalable dynamic energy model called DEAM (Barrett & Spataru, 2012; Spataru & Barrett, 2015) was developed since 2011 to investigate the energy demand and supplies of households, businesses, generators etc. connected to a local substation so as to simulate the possible future half hourly loads imposed on the substation. The changes in scale and shape of the current demand profile and forecast potential changes up to 2050 are assessed, given a mixture of efficiency and supply technologies that might be installed over this timeframe. A schematic diagram of the model's main logic is provided in Figure 8.

The main function of public energy suppliers is to deliver energy (electricity, gas, heat, etc.) to consumers to satisfy this demand. Annual energy

Figure 8. Model schematic illustration



consumption for different end uses is disaggregated temporally using activity profiles across the day, week and year. The load curves are generated for each different end use in order to allow for the effects of the weather and changes such as insulation, heat pumps or more efficient lighting. In order to investigate the system-wide effects of different scenario strategies, several substations were assessed in the simulation framework.

Load curves for consumers depend on their annual energy consumption for different end uses, activity patterns across the day, week and year, and on the responses of technologies. The load curves have been generated for each different end use in order to allow for the effects of weather and changes such as insulation, heat pumps or more efficient lighting. The loads may be aggregated by sector or by end use. Figure 9 shows the load curves aggregated to end use with DEAM model.

The model has the ability to operate at distributed network operator (DNO) level and at national levels of aggregation but is built up from an aggregation of individual agents from different databases. The model will be further expanded, for future changes please check http://www.ucl.ac.uk/energy-models/models/deam.

Example 4: Whole Energy System Modelling

The behaviour of all the main elements of the system should be considered since the operation of all subsystems and components are interdependent. All energy carriers, energy conservation and energy efficiency improvements action should be considered together. Such an example is the DynEMO model (Barrett & Spataru, 2011; 2013, 2015) which simulates the whole energy system, including people's behaviour and technologies, and calculates energy flows, operating costs and carbon emissions. The model can explore the technical feasibility and costs of efficient systems with high renewables and it includes scenarios showing the evolution of delivery dynamics for sample days in 2010 to 2050. Figures 10 and 11 show the energy delivery for 2010 and 2050 (Barrett & Spataru, 2013)

Figure 9. Load curves aggregated to end use with DEAM model

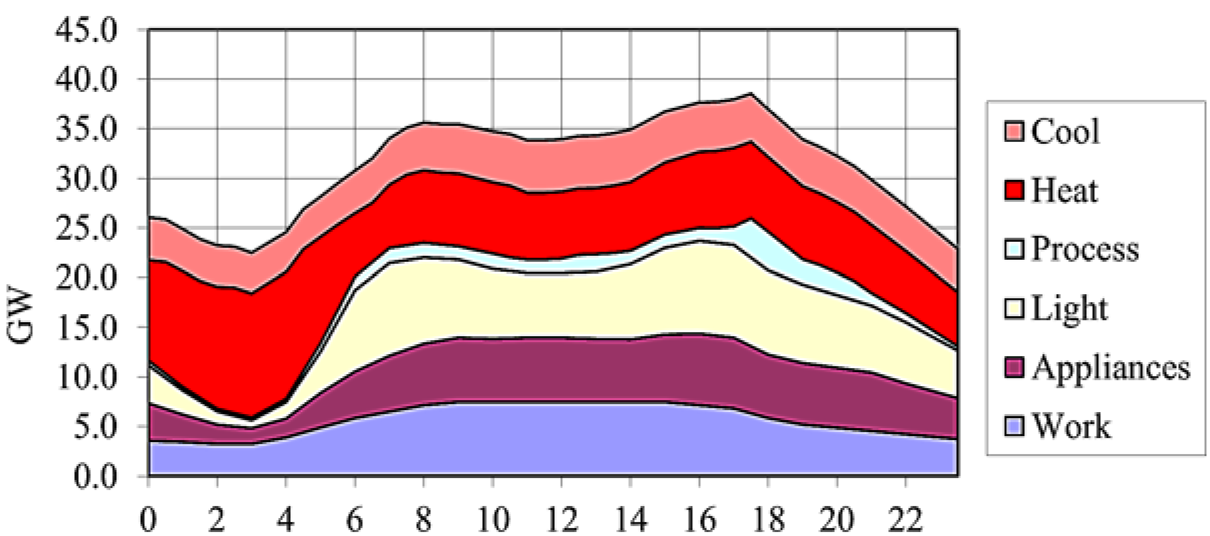


Figure 10. Energy delivery for 2010; 6 sample days: 1day/month; months 1,3,5,7,9,11
(Source: Barrett & Spataru, 2013)

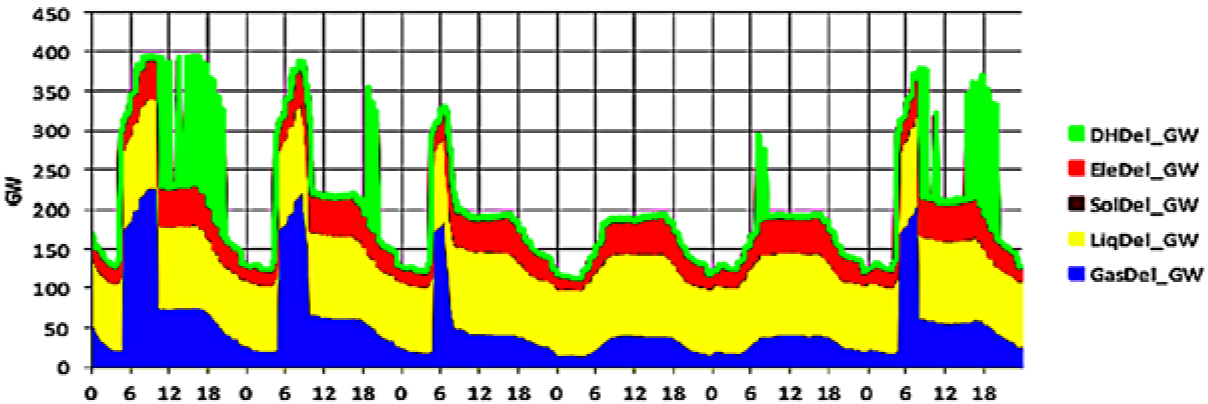
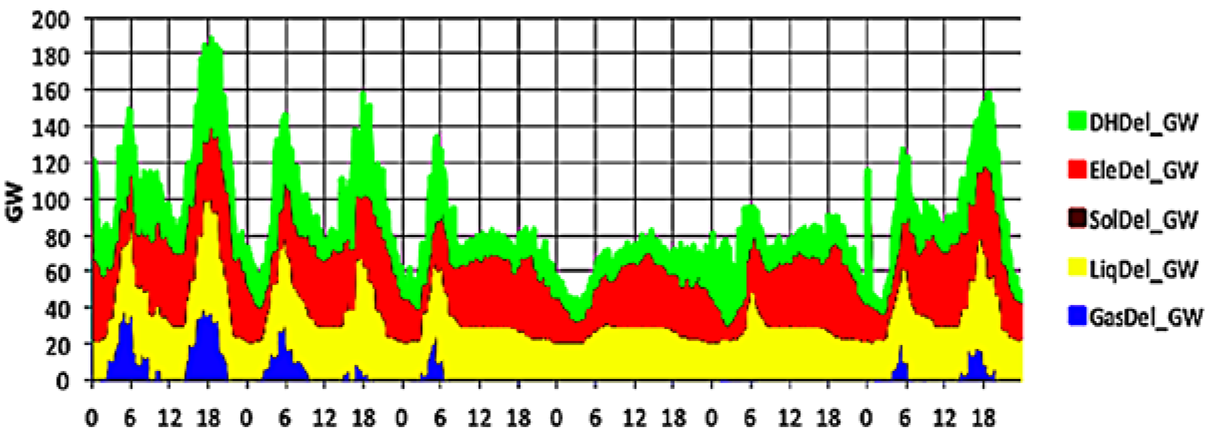


Figure 11. Energy delivery for 2050; 6 sample days: 1 day/month; months 1,3,5,7,9,11
(Source: Barrett & Spataru, 2013)



Barrett & Spataru, 2011 show that to meet carbon targets, fossil gas will be replaced in the future by a mixture of heat pumps, district heating, renewable. Furthermore, the model can be used to investigate energy security. This type of analysis could help to quantify dispatchable supply requirements for security in various subsystems – notably for heat, electricity and gas.

FUTURE RESEARCH DIRECTIONS

Models of energy systems or components have played a key role in formulating energy policy. However, as we move from developing strategies to implementing there is a need for a new generation of energy system models particularly at a system level for a number of reasons:

Connecting Disciplines

Whole system models which enable the full representation of demand side and supply side changes to be tested and integration across sectors, so that the impact of the interaction of policies in different areas on each other can be fully tested. For example, at present there is no real knowledge of the impact that changes to the building regulations have on upstream energy supply, nor are these savings calculated when building regulations are changed.

In the domain of energy system modelling there is a need for a better integration between physical based models of the energy system and econometric based models. Perhaps more important than the epistemological hierarchy is the fact that many interesting problems are mostly viewed as primarily physical issues with economic consequences that can be worked through as an addendum to the physical analysis. Their key features can be expressed more quickly, powerfully and elegantly in the language of physics and engineering than in the language of economics. The need for rapid progress in the analysis of many important energy questions therefore suggests the application of a set of primarily physics-based models both to complement and to support economics-based models. This allows to deliver detailed descriptions of specific interventions as well as their impact in terms of associated carbon emission savings. Rapid reductions in emissions imply rapid changes in both infrastructure and behaviour. Periods of very rapid change tend to render price information less or unreliable. Economic analysis can obscure the sometimes very simple results of the physics-based analysis of such problems. Conversely, many such problems are very effectively viewed from the viewpoint of mass flows through and into infrastructure, and are therefore ideally suited to physics-based analysis. For both of these reasons, there is an urgent need to develop physics-based models.

Representing Multiple Time Scales and View Points

System dynamics: as we move to implementation there is a real need to understand transient impacts better. Many system models look at annual or monthly energy use but not at short-term phenomena over days or minutes. As we move away from fossil energy sources the need for physics-based analysis to lead in the area of the transient analysis of systems arises from the fact that energy storage costs for electricity are orders of magnitude greater than for oil, gas and coal.

Allowing for Multiple Viewpoints

As eventually people rather than buildings use energy to maintain health, comfort and productivity. From this viewpoint a notion of service rather than infrastructure driven system models emerge. People can only occupy one space at any one time and there are massive potential savings to be had from just conditioning occupied spaces. Most system models do not allow these factors to be fully investigated and yet some of the easiest energy wins may come from moving to a person-based rather than infrastructure-based approach to analysing the energy system. Radical shifts in modelling perspective can probably be achieved more easily and transparently with physics-based models.

With regard to the economic system models, the conventional economic analysis of prices includes the concepts of price elasticity of demand and supply, both of which are non-linear functions (power laws) of changes in price. This formulation, coupled with time dependence and asymmetry in elasticities for positive and negative changes in price are sufficient conditions for the emergence of chaotic behaviour in energy prices. This could help to

1. Understand the nature and extent of such instabilities,
2. Investigate the possible impact of global oil and gas production peaking,
3. Relate instability in simulations to instability in the real world, and
4. Begin to explore the possibility of designing energy systems to minimise objective functions based both on price and price stability.

RECOMMENDATIONS AND CONCLUSION

As a main requirement, open and transparent features and a structure which allows models to be built on rather than new ones have to be created. This includes open data but also open standards in the involved disciplines as a key requirement to connect solutions at different scales. This will be further facilitated by common ontologies suitable to describe the different layers of meaning that will be required to cope with the future complexity. These will be relevant both for interactions of the real systems as well as for the model-based representation of these systems.

The notion of cyber physical systems implies that the frontier between real system components and simulation will become more and more blurry. This is, for example, already the case with algorithms used for load prediction in hardware components. This new point of view of integrated real time systems will induce an increase in the flexibility of the total system. On the other hand, many connected issues such as security will have to be reassessed.

Chaotic behaviour of simple heating systems: space heating accounts for a significant percentage of all energy use. Only very recently have researchers and agencies responsible for helping to deliver major carbon reductions, such as the Carbon Trust in UK, realised that traditional domestic heating systems are highly chaotic. The ability to model and hence better understand the chaotic behaviour of domestic heating systems will help to directly improve the efficiency of such systems and to suggest changes in the human infrastructure that would help indirectly.

There is a continuous evolution of the concept of 'integrated system modelling'. Many of the existing models have been improved or new models have been created. During the evolution of the energy system, significant improvements in details were observed, such as in the representation of different technologies for storage, conversion, transport and distribution of energy, energy demand and supply evolution at hourly levels. Significant improvements have been also made at market-level such as spot prices, hourly purchased quantities. However, new decision support tools are needed to address the challenge of the interconnection of different energy and emission markets.

Significant improvements have been seen in the usability of energy system models, with usage for both developers and planners, with more comprehensive and transparent procedures and with significant improvements on the visualization of the results. Yet most of the real decision makers are still not keen on using the models directly due to the amount of time and effort required to understand how to use these tools. The developers of energy models should also consider this aspect and provide handy and easy usage tools to decision makers.

The methodological adoption of integrated modelling and simulation for Smart Energy Systems must link geo-referenced simulation with grid infrastructure to represent systems and subsystems, considering the agent-based simulation of actors to represent system-wide communication. Eventually, such harmonized communication could include cyber physical systems and their operation in order to help to test new concepts and guide long-term investment decisions. Finally, the long lifetime of investments in new infrastructure and hardware will emerge as a driver for rapid action as it will require the right decision to be taken today, which will define the opportunities or limitations of tomorrow's smart energy system.

REFERENCES

Alanne, K., & Saari, A. (2006). Distributed energy generation and sustainable development. *Renewable & Sustainable Energy Reviews*, *10*(6), 539–558. doi:10.1016/j.rser.2004.11.004

Aydinalp, M., Ugursal, V. I., & Fung, A. (2002). Modeling of the appliance, lighting, and space cooling energy consumptions in the residential sector using neural network. *Applied Energy*, *72*(2), 87–110. doi:10.1016/S0306-2619(01)00049-6

Bahu, J.-M., Koch, A., Kremers, E., & Murshed, S. M. (2013). Towards a spatial urban energy modelling approach. In *Proceedings of 3D GeoInfo Conference* (pp. 27-29).

Barrett, M., & Spataru, C. (2011). DYNEMO: *Dynamic Energy Model, Model Documentation*. Retrieved from http://www.ucl.ac.uk/energymodels/models/dynemo

Barrett, M., & Spataru, C. (2012). *DEAM: Dynamic Energy Agents Model*. Retrieved from http://www.ucl.ac.uk/energy-models/models/deam

Barrett, M., & Spataru, C. (2013). Dynamic simulation of energy system. *Advanced Materials Research*, *622-623*, 1017–1021. doi:10.4028/www.scientific.net/AMR.622-623.1017

Barrett, M., & Spataru, C. (2013). Optimizing building energy systems and controls for energy and environment policy. In A. Håkansson, M. Höjer, R. J. Howlett, & L. C. Jain (Eds.), *Smart Innovation, Systems and Technologies, Sustainability in Energy and Buildings* (pp. 413–425). Berlin, Heidelberg: Springer-Verlag., Elsevier. doi:10.1007/978-3-642-36645-1_39

Barrett, M., & Spataru, C. (2015) DynEMo: A Dynamic Energy Model for the Exploration of Energy, Society and Environenment, UKSim 2015-17th International Conference on Mathematical/Analytical Modelling and Computer Simulation, Cambridge, March 2015

Catrinu, M. D. (2006). *Decision Aid for Planning Local Energy Systems, Application of Multi-Criteria Decision Analysis*. (Doctoral dissertation). Norwegian University of Science & Technology.

Eicker, U. (2006). System Management via Building and Supply System Simulation [Betriebsführung mittels Gebäude- und Anlagensimulation]. In *Proceedings of Workshop Concepts for Optimised Building Operation [Konzepte zur optimierten Betriebsführung von Gebäuden], Frankfurt*.

European Commission. (2014). *EU action on climate*. Retrieved from http://ec.europa.eu/clima/policies/brief/eu/index_en.htm

Evora, J., Kremers, E., Cueva, S. M., Hernandez, M., Hernandez, J. J., & Viejo, P. (2011). Agent-based modelling of electrical load at household level. In *Proceedings of Workshop on Complex Systems Modelling and Simulation*.

Faraji-Zonooz, M. R., Nopiah, Z. M., Yusof, A. M., & Sopian, K. (2009). A review of MARKAL energy modeling. *European Journal of Scientific Research*, *26*(3), 352–361.

GEA. (2012). *Toward a Sustainable Future*. Cambridge, UK: Cambridge University Press.

Huang, Y., & Brodrick, J. (2000). A bottom-up engineering estimate of the aggregate heating and cooling loads of the entire US building stock. In *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*.

IEA. (2011). *Technology Roadmap - Smart Grids*.

IEA. (2014). *The Power of Transformation - Wind, Sun and the Economics of Flexible Power Systems*.

Jebaraj, S., & Iniyan, S. (2006). A review of energy models. *Renewable & Sustainable Energy Reviews*, *10*(4), 281–311. doi:10.1016/j.rser.2004.09.004

Kadian, R., Dahiya, R. P., & Garg, H. P. (2007). Energy-related emissions and mitigation opportunities from the household sector in Delhi. *Energy Policy*, *35*(12), 6195–6211. doi:10.1016/j.enpol.2007.07.014

Keirstead, J., Jennings, M., & Sivakumar, A. (2012). A review of urban energy system models: Approaches, challenges and opportunities. *Renewable & Sustainable Energy Reviews*, *16*(6), 3847–3866. doi:10.1016/j.rser.2012.02.047

Koch, A., Girard, S., & McKoen, K. (2012). Towards a neighbourhood scale for low-or zero-carbon building projects. *Building Research and Information*, *40*(4), 527–537. doi:10.1080/09613218.2012.683241

Koch, M., Harnisch, J., Blok, K. (2003). *Systematische Analyse der Eigenschaft von Energiemodellen im Hinblick auf ihre Eignung für möglichst praktische Politik-Beratung zur Fortentwicklung der Klimaschutzstrategie*.

Kremers, E. (2013). *Modelling and simulation of electrical energy systems through a complex systems approach using agent-based models*. Karlsruhe: KIT Scientific Publishing.

Kremers, E., Durana, J., Barambones, O., & Koch, A. (2012). Towards complex system design and management in the engineering domain – the smart grid challenge. In *Proceedings of European Conference on Complex Systems*.

Nitsch, J., Pregger, T., Scholz, Y., Sterner, M., Gerhardt, N., von Oehsen, A., Wenzel, B. (2010) *Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global.*

Rath-Nagel, S., & Voss, A. (1981). Energy models for planning and policy assessment. *European Journal of Operational Research*, *8*(2), 99–114. doi:10.1016/0377-2217(81)90249-6

Soder, L., Hofmann, L., Orths, A., Holttinen, H., Wan, Y. H., & Tuohy, A. (2007). Experience from wind integration in some high penetration areas. *IEEE Transactions on Energy Conversion*, *22*(1), 4–12. doi:10.1109/TEC.2006.889604

Spataru, C. (2013). Energy: Centralisation versus Decentralisation in Global Systems. Science Orientation Paper. Retrieved from http://publications.lib.chalmers.se/records/fulltext/190487/local_190487.pdf

Spataru, C., & Barrett, M. (2012). The Smart Super-European grid: Balancing demand and supply. In *Proceedings of IEEE PES Innovative Smart Grid Technologies Europe*. Berlin.

Spataru, C., & Barrett, M. (2015) DEAM: A Scalable Dynamic Energy Agents Model for Demand and Supply, UKSim 2015 – 17th International Conference on Mathematical/Analytical Modelling and Computer Simulation, Cambridge, UK, March 2015

Summerfield, A. J., Lowe, R. J., & Oreszczyn, T. (2010). Two models for benchmarking UK domestic delivered energy. *Building Research and Information*, *38*(1), 12–24. doi:10.1080/09613210903399025

Van Dam, K., & Keirstead, J. (2010). Re-use of an ontology for modelling urban energy systems. In *Proceedings of Third International Conference on Infrastructure Systems and Services: Next Generation Infrastructure Systems for Eco-Cities*. doi:10.1109/INFRA.2010.5679232

VDE. (2014). *The German Standardization Roadmap Smart City* [Die Deutsche Normungs-Roadmap Smart City]. Frankfurt: VDE Verband der Elektrotechnik Elektronik Informationstechnik.

Wiechmann, H. (2008). Neue Betriebsführungsstrategien für unterbrechbare Verbrauchseinrichtungen: ein Modell für eine markt- und erzeugerorientierte Regelung der Stromnachfrage über ein zentrales Lastmanagement. Karlsruhe

Wood, A. J., & Wollenberg, B. F. (2012). *Power generation, operation, and control*. New York, NY: John Wiley & Sons.

ADDITIONAL READING

Brownsword, R. A., Fleming, P. D., Powell, J. C., & Pearsall, N. (2005). Sustainable cities - modelling urban energy supply and demand. *Applied Energy*, *82*(2), 167–180. doi:10.1016/j.apenergy.2004.10.005

CEMAT. (2006). CEMAT Glossary of Key Expressions Used in Spatial Development Policies in Europe. Document presented at the 14th Session of the European Conference of Ministers responsible for Spatial/regional Planning, Lisbon, Portugal.

Mendes, G., Ioakimidis, C., & Ferrão, P. (2011). On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. *Renewable & Sustainable Energy Reviews*, *15*(9), 4836–4854. doi:10.1016/j.rser.2011.07.067

Pearmine, R., Song, Y. H., & Chebbo, A. (2007). Influence of wind turbine behaviour on the primary frequency control of the British transmission grid. *IET Renewable Power Generation*, *1*(2), 142–150. doi:10.1049/iet-rpg:20060003

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable & Sustainable Energy Reviews*, *13*(8), 1819–1835. doi:10.1016/j.rser.2008.09.033

Yamaguchi, Y., & Shimoda, Y. (2010). District-scale simulation for multi-purpose evaluation of urban energy systems. *Journal of Building Performance Simulation*, *3*(4), 289–305. doi:10.1080/19401491003746621

Young, P., Parkinson, S., & Lees, M. (1996). Simplicity out of complexity in environmental modelling: Occam's razor revisited. *Journal of Applied Statistics*, *23*(2-3), 165–210. doi:10.1080/02664769624206

KEY TERMS AND DEFINITIONS

Complex Systems: A system made up of a number of connected objects, which shows a number of properties which include nonlinearity, emergence and interactions – often these systems are referred to as complex adaptive systems.

Integrated Planning: Integrated planning (as opposed to sectorial planning) is a process involving the drawing together of level and sector specific planning efforts which permits strategic decision-making and provides a synoptic view of resources and commitments. Integrated planning acts as a focal point for institutional initiatives and resource allocation. In the context of integrated (or comprehensive) planning, economic, social, ecological and cultural factors are jointly used (CEMAT, 2006).

Multi-Scale Modelling: Multi-scale modelling describes an approach to representing systems that have relevant features or interactions at different scales. Mostly temporal or spatial scales are considered.

System: A system is usually understood as a number of related individual elements, which can be understood as a whole when regarded in the context of a specific purpose.

System Dynamics: System Dynamics is a dynamic modelling approach at system level which is primarily used to understand interconnected systems and their evolution over time. Basic elements to represent the systems are internal feedback loops as well as stocks and flows.

System of Systems: A system of systems is an organisational structure in which individual decentral or distributed systems are coupled together and interact across the individual systems' boundaries.

Chapter 8
ICT-Based Solutions Supporting Energy Systems for Smart Cities

Wolfgang Loibl
AIT Austrian Institute of Technology, Austria

Brigitte Bach
AIT Austrian Institute of Technology, Austria

Gerhard Zucker
AIT Austrian Institute of Technology, Austria

Giorgio Agugiaro
AIT Austrian Institute of Technology, Austria

Peter Palensky
Delft University of Technology, Netherlands

Ralf-Roman Schmidt
AIT Austrian Institute of Technology, Austria

Daniele Basciotti
AIT Austrian Institute of Technology, Austria

Helfried Brunner
AIT Austrian Institute of Technology, Austria

ABSTRACT

This chapter describes ICT solutions for planning, maintaining and assessing urban energy systems. There is no single urban energy system, but – like the city itself – a system of sub-systems with different scales, spatially ranging from buildings to blocks, districts and to the city, temporally ranging from real time data to hourly, daily, monthly and finally annual totals. ICT support must consider these different sub-systems which makes necessary dividing the chapter into different sections. The chapter starts with framework conditions and general requirements for ICT solutions, and continues discussing urban development simulating models. Then decision support tools are described for energy supply and demand as well as for energy efficiency improvement assessment. Later further instruments for Smart Grid-, district heating- and cooling-planning, as well as demand side management are addressed. In the final section tools are discussed for building automation systems as smallest physical entity within the urban energy system.

INTRODUCTION

With respect to urban energy planning, ICT systems and solutions address all Information- and Communication Technology-based instruments and features which (i) simulate the urban system as a spatial framework and the (urban) energy system behaviour for *ex ante* assessment of applying energy strategies and measures, (ii) monitor energy supply and consumption as well as the state of the energy generation and transmission system, and (iii) manage – which is control and

DOI: 10.4018/978-1-4666-8282-5.ch008

adaption of the energy supply and – if committed – also the demand side, to improve the future energy system performance: to enhance energy efficiency, mitigate environmental impacts, reduce supply and transmission costs and finally strengthen energy supply security.

Integrated city planning and management are crucial to initiate transformations of urban development, urban governance and infrastructure required to become a Smart City. There exists a wide range of ICT solutions for different purposes, audience and scales – spatial as well as temporal – to support these urban transformation processes. One urban planning approach involves supporting a holistic view by integrated modelling – i.e. modelling the city as a system of systems considering all important interdependencies. A different approach involves supporting sectorial planning, applying solutions which are tailored for experts in the sector to provide answers to technical questions, as well as assessing the related impact. Both approaches support decision makers in evaluating different options and effects of energy supply technologies and changes in demand. Thus decision support tools play a crucial role for performance assessment, benchmarking and easy-to-understand visualisation of different transformation scenarios and their economic, environmental and social impacts (Tommis & Decorme, 2013).

Going into detail would require a complete book instead of a single chapter. Taking into account the wide range of available and suggested ICT solutions and the space available in this chapter to debate the most relevant topics, we have divided the chapter into several sections to give an overview. Keirstaed (2011) has carried out a classification of models related to urban systems and energy systems, which gives some orientation for structuring the chapter:

- *Urban development models* – including urban growth, land use change and transportation models. These models are the key to understanding urban energy topics as they typically model structure and activities in a city, finally used to estimate the energy demand for these activities.
- *Policy assessment models* examine the city and try to assess long-range policy goals, e.g. to identify which measures and technologies might meet a given carbon target most cost-effectively.
- *Technology design models* target the energy supply and demand side, dealing with optimisation of energy supply technology, supply mix and costs and finally improvements to consumption shapes to better balance supply and demand.
- *Building design (and automation) models* look at the performance of buildings.

Following Keirstaed's classification, this chapter is divided into the following sections:

- Background and requirements for ICT solutions related to energy and Smart Cities
- General ICT solutions for urban development, as a framework for energy planning
- ICT solutions for energy system planning enabling smart urban development
- ICT for energy supply solutions: Smart Grids, district heating
- ICT for demand-side energy management
- ICT for building automation
- Future research directions
- Conclusions and outlook.

BACKGROUND: GENERAL FRAMEWORK CONDITIONS AND REQUIREMENTS FOR ICT SOLUTIONS FOR INTEGRATED SMART CITY DEVELOPMENT

The transition of cities towards becoming smart requires an appropriate process which must involve a wide range of stakeholders (citizens, energy service providers, real estate developers, NGOs, etc.) and experts from various administration bodies and finally policy makers. A Smart City transition process typically involves three stages:

- The first is the elaboration of a Smart City Transformation Agenda with drafting, negotiation, and finally the commitment of a Smart City Strategy addressing the overall view on a city-wide scale, long-term horizon and integrating all relevant topics, e.g. space heating and cooling, street lighting, mobility, industry, communication, system control, etc. (Non-energy issues are also part of such a Smart City Strategy, but we focus on energy here.)
- The second stage deals with the (on-going) implementation of measures to achieve the objectives of the transformation agenda through a set of activities.
- The third stage refers to the assessment of the progress achieving the defined energy efficiency, saving target and renewable energy ratio objectives.

Energy performance improvement activities are carried out frequently at building to block levels in neighbourhoods of a city. The selected measures must be tailored for the particular area to seek approval from the involved stakeholders, experts and policy makers.

Some activities for improving urban energy performance, e.g. those related to mobility and transportation, require decisions not on a local scale, but on a city-wide scale, considering city-wide targets and consequences. Thus such an improvement process requires decisions and related (ICT-based) support for different scales related to the different viewpoints of interest groups, from the personal view focussing on a single house, to the developers' view, interested in delivering an economically successful and technically feasible project for a district, and finally to the political representatives' view, as they must consider the citizen's personal desires and the wellbeing of the entire city in terms of environment, society and economy. So the ICT solutions must satisfy various clients regarding energy-related and urban-development-related decisions on the implementation of strategies and measures, illustrated in the following paragraphs.

In the European research project on energy efficient neighbourhoods (IREEN), interviews were carried out with around 30 senior city and regional representatives responsible for urban energy systems across Europe . The questions refer to current urban energy-related ICT use, ICT systems and infrastructure and the needs and benefits the interviewees hoped to gain. The requirements for ICT systems to support cities' transitions towards smart energy use are very diverse, as the following sample, extracted from Tommis and Decorme (2013), shows:

Barcelona (Spain) summarizes:

Our objective is to be a self-sufficient, independent city in terms of energy. Being capable of providing as much local and renewable energy as possible, promoting a reduction on energy demand and, at the same time, being able to produce economic growth." (Tommis and Decorme, 2013). A set of requirements on ICT solutions have been listed that enable the following items: buildings' energy efficiency, improvement of public building infrastructure to save energy, smart monitoring, and easy tools to check energy efficiency in buildings.

Cardiff (Wales) recognizes ICT as a key enabler of efficient services: supporting to take energy efficiency measures to the next level with a holistic view of the integration/interoperability of systems beyond energy and water; developing infrastructure control, applying smart meters and intelligent maintenance, along with wider relationships with citizens and businesses.

Gent (Belgium) suggests an open data warehouse to collect all energy data: "For such a central plat-

form we need requirements and a key framework for data formation and clarity on legal boundaries. Each stakeholder, including the citizen, can share information and people will only have access to the platform when they also deliver data. (…) We can also use information from our 3D models of the city, such as the shade of buildings for the calculations on effectiveness of solar panels. (Tommis and Decorme, 2013).

So we address the set of ICT tools as a backbone to provide services to an urban community at all levels, providing appropriate tools – addressing the city as the physical, social, technical and political framework and the related energy demand and supply management. Smart ICT systems must secure privacy and must not be experienced as a surveillance framework, but as a supporting instrument allowing user communication and feedback and ensuring that the system reacts appropriately to improve user satisfaction.

ICT SOLUTIONS FOR URBAN DEVELOPMENT AND DESIGN

Before discussing details for ICT solutions for energy planning, we start with an introduction on common tools for generic urban development analysis and modelling. Energy planning has a close relationship with urban planning and urban development, as planning strategies (development directions) and urban design (zoning, height and density regulations, distribution of urban functions, transportation network) influence energy consumption to a certain extent. This makes it necessary to carry out both energy and urban planning in parallel to make use of positive dependencies for improvement of both systems the urban and the energy system. Thus urban-planning-related tools serve as a backbone for energy planning.

Integrated and sustainable urban development is an issue which can profit greatly from ICT tools. Applications may address various activities which are typical for urban policy making processes: issue identification, impact analysis, decision support, policy implementation and evaluation. To understand the physical impacts of planning decisions, detailed insights into the urban system structure and their interdependencies are necessary. Various ICT-related planning and analysis tools have been developed, helping to prepare decisions and evaluate impacts through visualization and quantitative analysis of development scenarios (Boyd & Chan, 2002). To allow detailed impact assessment, we must consider not only the scope of effects but also the distance or vicinity of energy generation and energy use hot spots and the volume of receptors exposed to environmental pressure (vegetation, wildlife, inhabitants etc.). This requires spatially explicit scenarios to be modelled by integrating various measures.

Although urban simulation tools have often been enriched with selected GIS functionality, improvement is still welcome. From the academic side, great efforts have been put into developing concepts which facilitate the integration of urban planning tools with GIS technologies, and the whole topic is still the subject of intense research work.

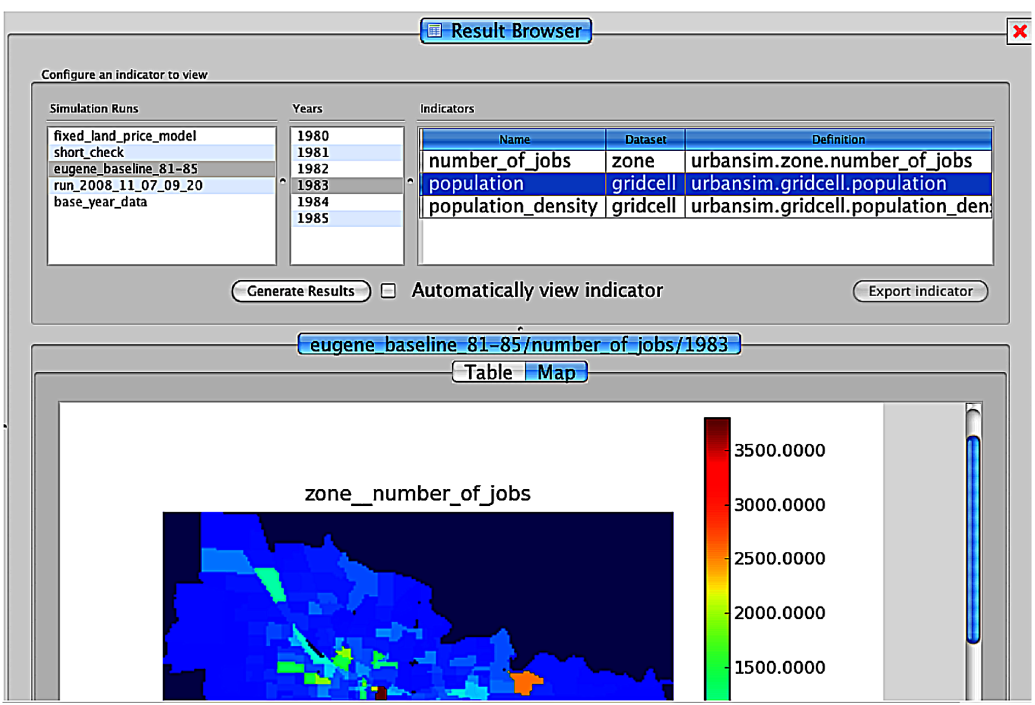
A promising tool for urban development simulation is "UrbanSim", originally developed by Paul Waddell and continuously improved at the University of Washington and the University of California, Berkeley (Waddell, 2000). UrbanSim is a state-of-the art simulation system for supporting planning and analysis of urban development, incorporating interactions between land use, transportation, economy and the environment. UrbanSim adopts a micro-simulation approach: households, businesses or jobs, buildings, and land areas are represented through individual agents, addressing different spatial entities to be selected, ranging from buildings and parcels to grid cells and districts. The model simulates urban development dynamics through the interaction of many actors, making decisions within the urban markets for land, housing, non-residential space and transportation.

The user interacts with the tool to create scenarios, specifying alternative population and economic development expectations, land use policy assumptions, and other exogenous inputs. The tool is thus intended for use by planning authorities and researchers interested in exploring the effects of planning policy choices, including transport modes and accessibility, housing affordability, greenhouse gas emission targets or open space and habitat protection. Results can be viewed through a results manager (Figure 1) .

The tool has been applied in more than 50 metropolitan areas on all continents. UrbanSim is licensed as open source software based on the Open Platform for Urban Simulation "OPUS", designed for self-programming and extension. As the model is rather complex it cannot be easily operated by non-experts, needing assistance by scientists and trained planners. If not used in academic environments but in city administrations, applications are usually supported by consulting firms such as Urban Analytics which specialize in UrbanSim modelling and related input data harvesting. A re-engineered implementation, prepared by Synthicity, which incorporates 3D visualisation, is now available.

A further comprehensive tool has been developed by the Dutch Technology Research Organisation TNO – "Urban Strategy". This tool does not simulate urban development as an automatic generation process, but makes it possible to conduct impact assessment of urban planning decisions, applying a set of models which simulate traffic, energy use, air quality, noise, groundwater and other topics addressing sustainability. The tool must be commercially obtained by TNO. It has not been designed to be sold as a standalone product but as a support instrument for TNO consulting services provided to city authorities.

Figure 1. UrbanSim result browser, Urban Analytics Lab
(Source: http://www.urbansim.org/downloads/manual/dev-version/opus-userguide.pdf)



Like UrbanSim, Urban Strategy requires a great deal of input data following a standardized data structure. Tool application requires training and the output requires advice regarding interpretation. Much emphasis has been put into result visualisation capabilities. Model results are presented as 3D presentations, 2D maps and charts and graphs providing an overview through key performance indicators. The tool has been applied since 2007 for different planning projects in various (mostly Dutch) cities or regions, which are clients of TNO.

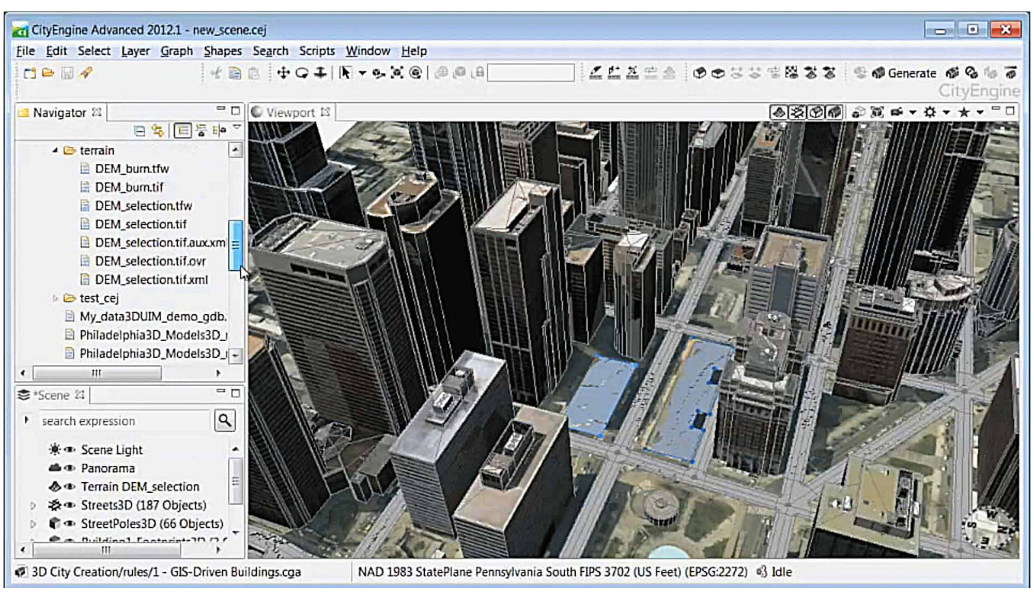
Besides these complex applications requiring intensive guidance and training through the developing institutions, easier to use commercial products have also been developed recently to create 3D city models, supporting interactive planning, urban design and presentation. A well-known tool is "ESRI CityEngine". A remarkable feature of an earlier CityEngine version (as developed by Procedural before the company becomes part of ESRI) – the automatic creation of virtual cities (Parish & Müller, 2001) – has been excluded, so ESRI CityEngine is now an urban design and 3D-visualization tool. It is possible to create a virtual city by loading existing GIS or CAD data and by interactively allocating new buildings or modifying existing ones with convenient 3D-editing functionality – 3D extrusion, texturing, lighting, shading and adding property-attributes (see Figure 2).

ICT SOLUTIONS FOR ENERGY POLICY SUPPORT IN TERMS OF SMART URBAN DEVELOPMENT

This group of instruments focuses on *ex ante* policy evaluation of selected strategies through modelling scenarios by adding virtual implementations of possible energy-related measures such as efficiency improvement of the building stock, new technologies for energy demand reduction and distributed (renewable) energy generation, substitution of fossil energy carriers, finally assessing the impact on energy performance, use of renewables and greenhouse gas mitigation.

Growing urbanisation and the demand for higher living standards require appropriate ur-

Figure 2. ESRI CityEngine user interface, screenshot from tutorial video for creating a new scene (Source: http://www.esri.com/software/cityengine/features)



ban development strategies and energy policies addressing the entire energy-cycle (e.g. generation, supply, consumption and related spatial and institutional framework conditions). Today, urban energy planning is facing a set of questions such as:

- How to choose between different types of energy generation and distribution technologies (e.g. central vs. distributed energy generation, exploitation of renewable energy sources like solar- groundwater-, wind- and geothermal energy)?
- How to deal with the construction and extension of supply and utility infrastructures?
- How to increase energy efficiency (e.g. retrofitting technologies for buildings) and how to simulate it?
- How to locate energy-inefficient buildings?
- How to evaluate (spatially and temporally) the energetic performance of a city or district?
- How to simulate different scenarios according to different energy policies?
- How to evaluate the impact of these measures?

Answering these questions demands a holistic approach for strategic energy-planning from the perspective of both the city administration and energy providers. In parallel, participatory, integrated and sustainable urban development is an issue which can profit a lot from ICT-based tools.

Nowadays, precise information about all the physical and functional characteristics of a single building to the urban scale is theoretically feasible, but cannot be carried out with the standard computer resources and data availability for an entire city. In addition data privacy is an issue and city-wide energy consumption data at the building level is – in most cities – not available. Hence it is necessary to adopt a top-down approach, where the energy characteristics of buildings at the block or city level are obtained or estimated in different ways. One possibility is to take statistical data describing the building size and building age distribution and further population and household data at census-district level serving as proxy data to estimate energy consumption.

There exists a variety of tools for decision support in urban energy planning. An overview of such tools can be found, for example, in Connolly et al. (2010). Here we describe two exemplary ICT solutions for different levels of detail and for different purposes.

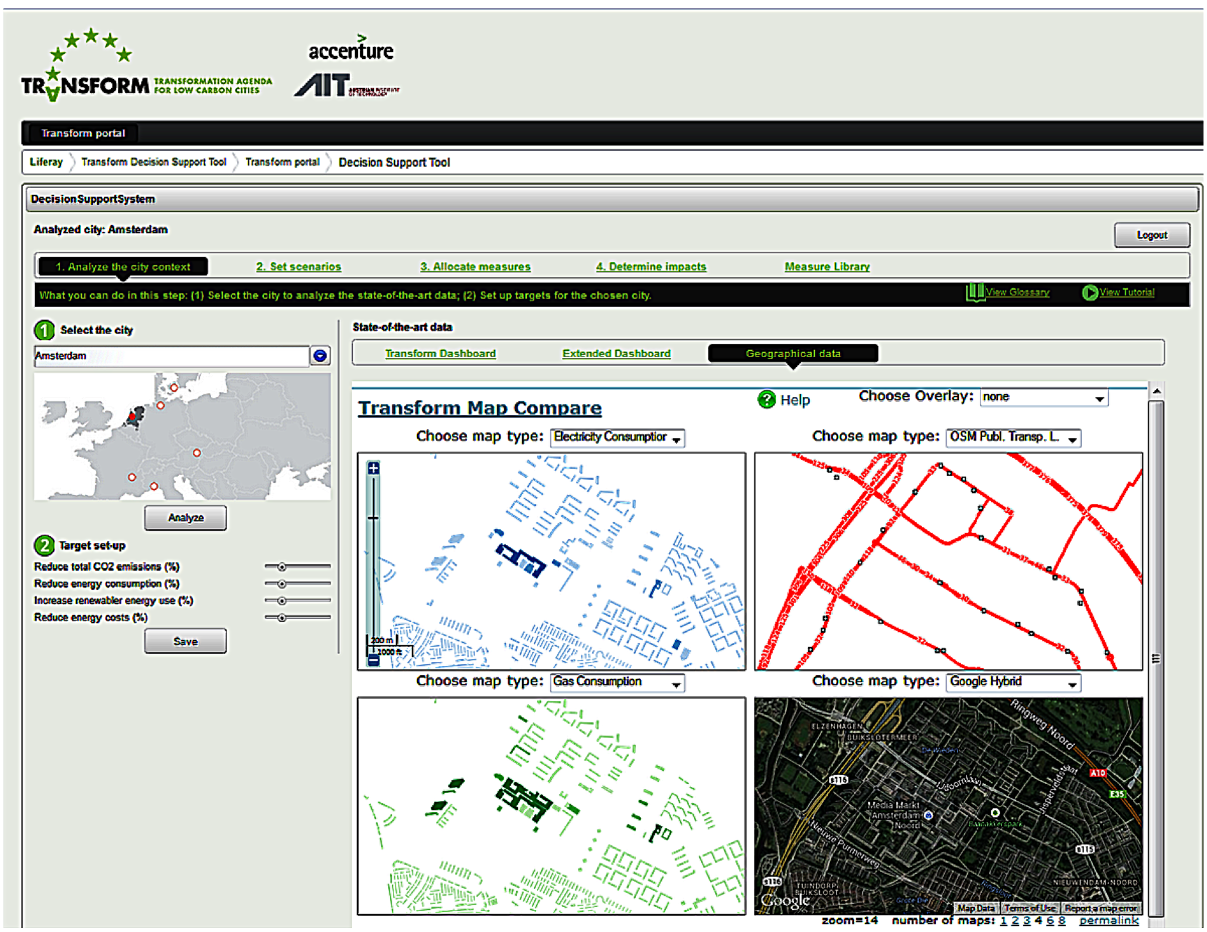
The TRANSFORM decision support tool carried out within the TRANSFORM project – operated by two teams: AIT (the Austrian Institute of Technology) and Accenture B.V. Netherlands – is a complex instrument which allows an integrated view of energy generation, supply and demand as well as simulating measures for energy efficiency improvement, addressing an entire city at district level and a selected district at block or – if data is available – building level (Loibl et al., 2014). The tool is designed as a flexible modelling framework which allows the allocation of interactively defined areas for measure implementation and can be extended through designing virtual measures using a measure editor. Spatial allocation is enabled through GIS functionality. Measure applications regarding energy efficiency changes, energy carrier selection and energy supply technology changes are simulated to evaluate possible impacts at the local scale and their contribution to Smart City targets. The data considered consists of:

- City layout, with focus on buildings and blocks containing specifications (e.g. building age) to estimate energy demand for heating and cooling and the energy efficiency improvement potential,
- Population: details of the population and households to estimate electricity consumption if data consumption data are missing,
- Energy consumption and (distributed) production potential by energy carrier.

The tool gives stakeholders a deeper insight into the impact of energy use improvement measures regarding the city's or district's performance for energy efficiency, energy consumption, CO_2 emissions and energy supply. Figure 3 shows the start page of the GUI with scenario selection and measure allocation and impact assessment features.

As the tool must support the planning process in a city administration, the sequence of steps made during such a decision process is included into the tool's usage flow: Step 1 involves selecting the spatial context: the higher the level of detail of the explored data, the more detailed the analysis can be. Step 2 refers to the selection of a scenario considering current and future framework conditions for energy demand and supply, as well as future changes (e.g. through urban growth, energy prices). In step 3 measures are defined by a measure editor (adding conditions, variables and factors to model the measure) and allocated through an interactive map. The final step 4 determines impacts by simulating measure implementation over time to be explored through maps and diagrams. The results concentrate on defining and allocating defined measures and on KPI calculation regarding environmental impacts, costs and savings as well as on comparison of scenarios and cities. The results provide annual data and to some extent monthly data. Currently the mapping is related to 2D views.

Figure 3. User interface of the TRANSFORM tool – start page
(Source: Loibl et al., 2014)



With the growing availability of virtual 3D city models in recent years, energy system modelling, analysis and simulation processes, 3D analysis and visualisation are now more and more incorporated into energy planning tools. For 3D city modelling, CityGML (Kolbe, 2009) is a common standard today for storage, manipulation, presentation and data exchange of virtual 3D city and landscape models (www.citygml.org). The standard defines a generic model describing the geometry, topology, semantics and appearance of 3D objects in urban environments, with five possible geometric and semantic levels of detail (LoD). Also included are generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. The benefits tied to a spatio-semantically coherent urban model (Kolbe, 2009) are multiple, as well as the possibility of exploiting such a model for further, more advanced applications ranging from urban planning, augmented reality, utility network management (Becker et al., 2013) to energetic simulation tools (Agugiaro et al., 2012). The term virtual "3D city model" does not only refer to geometry (e.g. height, volume, position of objects), but also to semantics (e.g. building type, usage, construction date) and topology (e.g. adjacency to other buildings, shared walls).

By means of "enriched" virtual city models, information regarding the building (roof, wall and window surfaces, amount of shared surfaces, year of construction, building size and typology, building use, etc.), as well as other data about the inhabitants, local climate, etc. can be used to estimate an energy balance between heat losses and gains. Further analyses can be performed to estimate the potential gains from building retrofitting and the adoption of new technologies or renewable energy sources. City objects can be connected by external links to specific ancillary data (e.g. cadastral data, solar yield estimation of the roofs). The underlying idea regarding the spatio-semantic modelling of a city is that many urban entities are physical objects occupying space in the real world. Elements, like buildings, can be subdivided into smaller entities (e.g. rooms), for detailed modelling.

The use of 3D city models (thus enriched with as many external data sources as possible) has been proposed and investigated e.g. by Carrión et al. (2010) and Strzalka et al. (2011), who have proposed algorithms to estimate the heating energy consumption of buildings. The Energy City project, located in Frederikshavn (Denmark), involved making a 3D city model to act as an awareness tool allowing politicians and citizens to visualise and understand the change of energy consumption and energy sources in an urban environment over a period of time (Kjems & Wen, 2011). The "Energy Atlas Berlin" project (Krüger & Kolbe, 2012) resulted in a city-wide energy atlas, focussing originally on heating energy consumption for buildings, but with the primary goal of introducing the concept of an integrated framework for transparent planning processes at all levels of decision-making in cities concerning strategic energy-planning. Energy Atlas Berlin later extended its approach from heating energy demand to total energy demand estimation, integrating other sources of energy consumption (e.g. warm water and electricity) and finally production (e.g. solar potential of the roofs, geothermal heat potential) (Kaden & Kolbe, 2013). Similar approaches have been applied in other cities, namely London in the UK and Trento in Italy (Agugiaro, 2014) (Figure 4).

Developed by École polytechnique fédérale de Lausanne (EPFL), "CitySim" is a sophisticated energy planning tool for districts, focusing on heating energy and serving as a decision support for urban energy planners (Robinson et al., 2009). CitySim comprises a Graphical User Interface to facilitate the buildings' 3D shape for urban districts (making it possible to work with several hundred buildings) and attribute the buildings' thermo-physical properties as well as visualize simulation results. It also includes a CitySim Solver for simulating buildings' energy supply and

Figure 4. Example of heating energy demand estimation for residential buildings in the city of Trento, Italy (Source: Agugiaro, 2014).

demand for space conditioning. Energy supplies from renewable sources can be determined for the buildings, including radiation exchange driven by the urban environment, making it possible to work at different temporal resolutions. A range of graphical tools support energy consumption analyses to identify the buildings' performance improvement potential.

The tool can be requested for free from EPFL's CitySim-website as a basic version. Field surveys within residential and non-residential buildings, accounting for a range of commonly used heating, ventilation and air conditioning systems as well as further building energy analysis software, have been used to validate models and algorithms implemented in CitySim. The buildings are stored in CityGML standard allowing 3D viewing as well as shape, orientation and size related analysis. Figure 5 shows the short wave radiation exposure of the buildings' walls and roofs.

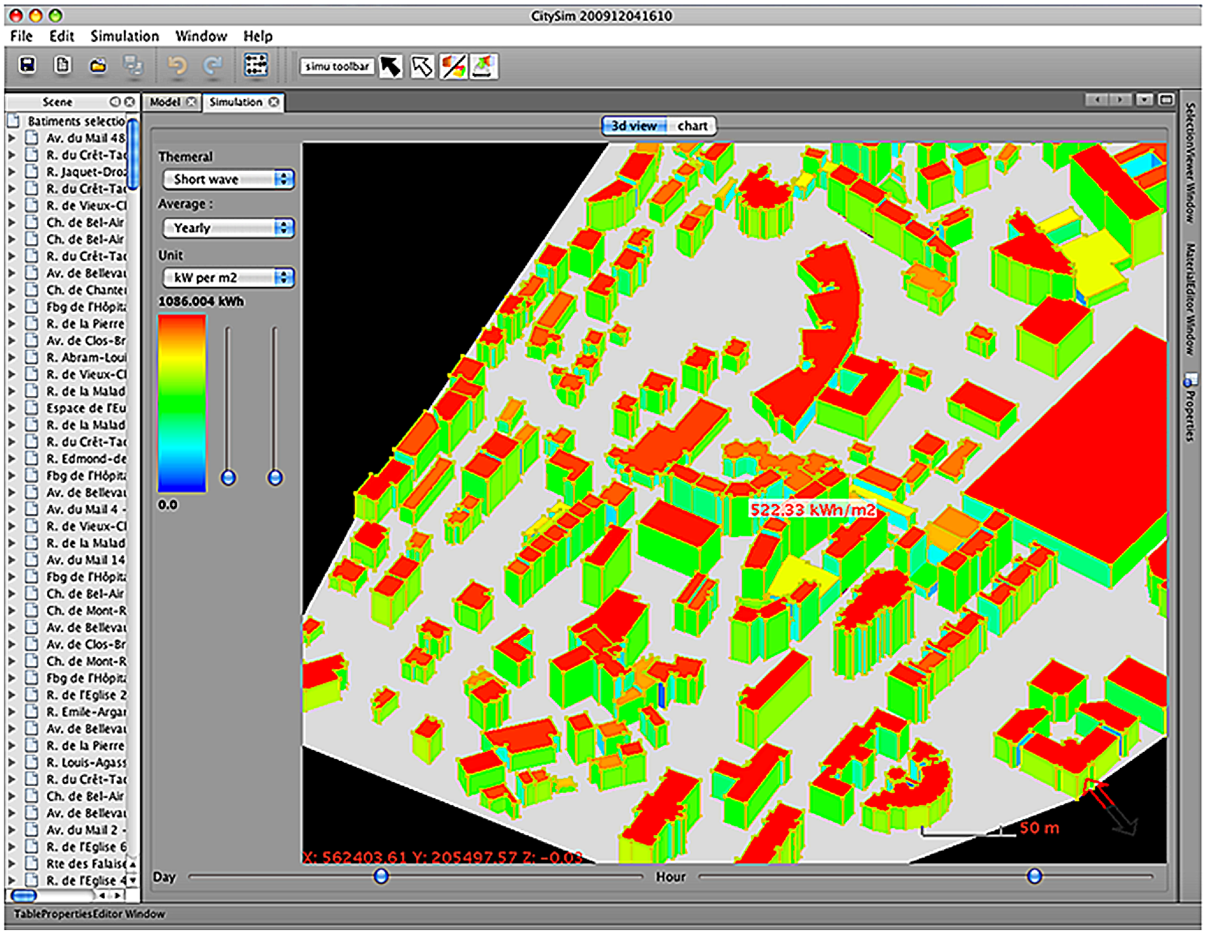
Further software tools supporting the energy planning process are EnergGIS (Girardin et al., 2010) SynCity (Keirstead et al., 2009) or ReMAC (Metrex, 2014), working at different spatial levels.

The following sections describe ICT solutions with a close link to supply technology which are not necessarily tailored to urban energy systems. Nevertheless they are important elements to enable Smart City progress in terms of energy.

ICT SOLUTIONS FOR ENERGY SUPPLY: SMART GRIDS

The term Smart Grid is often used in the context of future planning and electricity network operation. Referring to IEA (2011), a Smart Grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation

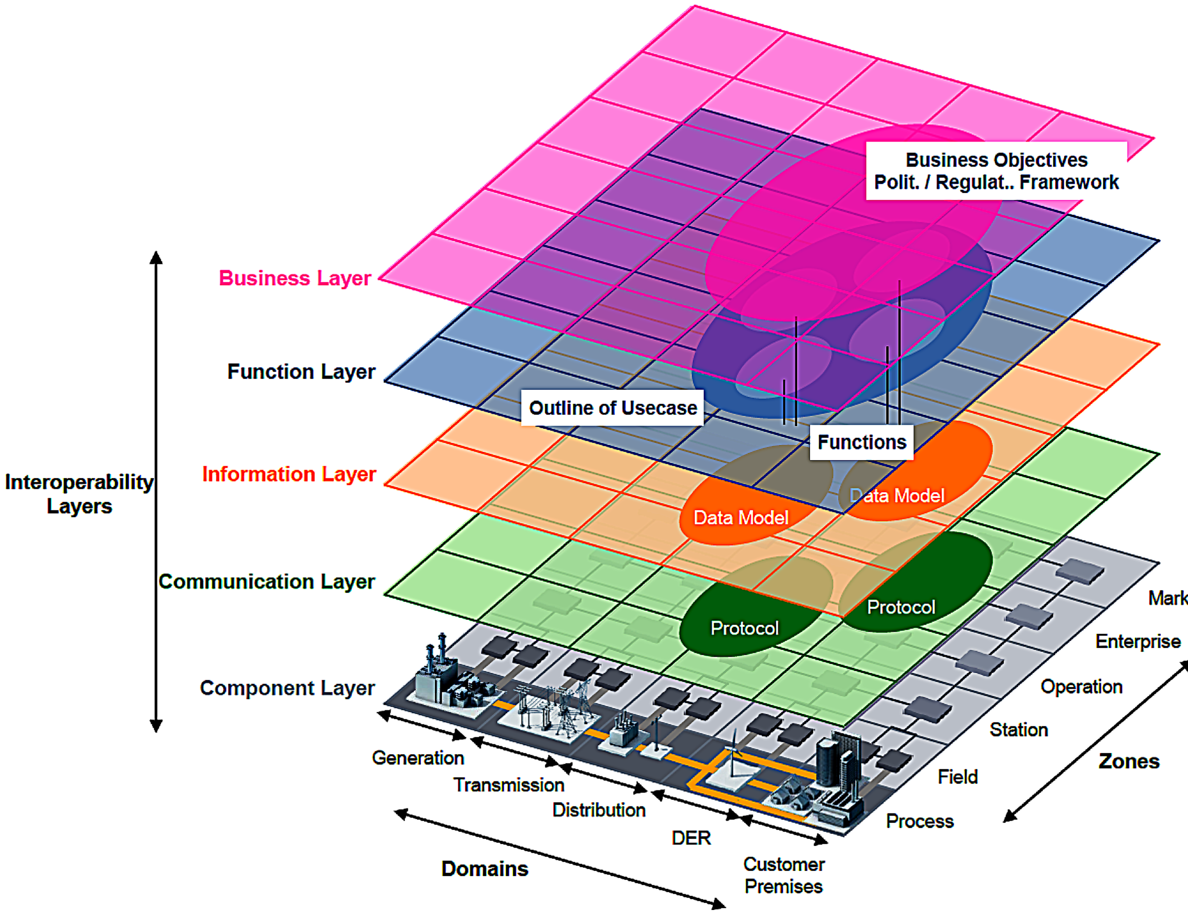
Figure 5. CitySim analysis screenshot: buildings exposed to short wave radiation volume
(Source: http://citysim.epfl.ch/).



sources to meet the varying electricity demands of end-users. Smart grids thus co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximising system reliability, resilience and stability (IEA, 2011). Reasons for introducing Smart Grids and related ICT are various: integration of renewable energy and related CO_2-reduction, improving supply security, rural electrification, peak-load-reduction; renewables integration, reduction of electricity losses.

In terms of managing the different actors and technologies in the electricity network, ICT is the key enabler. The CEN-CENELEC-ETSI Smart Grid Coordination Group (2012) provides a technical reference architecture, defining the functional information data flows between the main domains of this energy supply system (see Figure 6). The architecture merges the five interoperability layers (business, function, information, communication and components) with the two dimensions of the Smart Grid Plane, i.e. zones (representing the hierarchical levels of power system management: process, field, station, operation, enterprise and market) and domains (covering the full electrical energy conversion chain: bulk generation, transmission, distribution, DER and customers' premises).

Figure 6. SGAM framework
(Source: CEN-CENELEC-ETSI Smart Grid Coordination Group 2012)

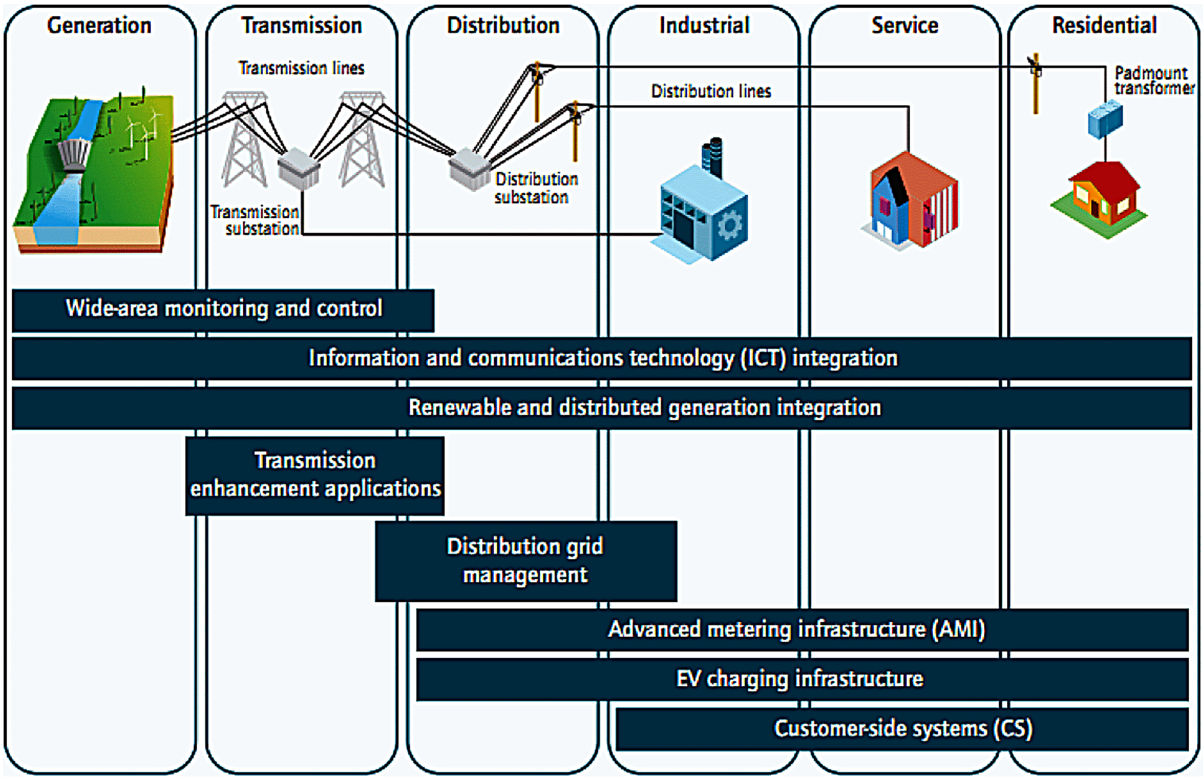


Information technology enhances the traditional power grid infrastructure by enabling new applications alongside the transport of electrical energy. The ICT infrastructure supports the exchange of information between all involved actors and allows them to access data, services or devices available in the power grid. Access must be ensured, providing secure and reliable protection complying with data protection requirements. Smart grids thus involve various application domains as Figure 7 illustrates.

The realization and handling of Smart Grids is strongly system based. As shown in Figure 7, Smart Grids have a distinct influence on the kind of energy transmission and distribution, network components, generation, consumption and storage as well as power markets and all associated businesses. As network operation is a regulated market in many countries, regulatory aspects must be considered. Without competition in the market as an innovation trigger, technology improvement efforts are modest. Ultimately, three topics are crucial for the future operation of electricity networks: the technical, the economic (commercial) and the regulatory framework.

For Smart Grids the following measures depend on a system-wide IT infrastructure (Acatech, 2012):

Figure 7. ICT application domains in the smart grid
(Source: OECD, 2012)



- Integration of renewable energy
- Peak load reduction (adaptation of the load profile)
- Transformation into a bi-directional supply structure (consumers are also producers)
- Storage capacities enabling new services and products (e.g. electric mobility)
- Dynamic pricing within the energy market (for all participants)

Table 1 gives an overview of Smart Grid features and ICT applications.

Since electricity networks have a higher hosting capacity for renewable energy resources in an urban environment, the main focus is on optimizing the electricity supply at neighbourhood, district as well as city level. In general a Smart Grid is not a final product or single solution; it is more a process of improving and maximizing the utilization of existing electricity grid infrastructure and of designing future grids in order to be prepared for future development, securing high supply quality in consideration of the capital expenses (CAPEX) by avoiding or delaying network reinforcement as well as taking into account the operational expenses (OPEX) of the infrastructure.

Effective load management requires real-time information about electricity generation as an input to the grid and load on the grid (i.e. electricity demand). Transmission lines transport electricity at high voltages from bulk power plants to substations where electricity feeds into regional and urban distribution systems. Balancing load and voltage across a transmission and distribution grid requires the ability to react to sudden changes, e.g. drops in output or peaks in demand.

Grid operators already use ICT-based applications, mainly to monitor the status of national

Table 1. ICT Applications of smart grid features and applications

Electricity Sector Challenges	ICT Applications
Generation	
Renewable energy generation	• Smart meters • Vehicle-to-grid (V2G) and grid-to-vehicle (G2V)
Distributed, small-scale electricity generation	• Virtual power plants • Vehicle-to-grid (V2G) and grid-to-vehicle (G2V) • Smart meters
Transport (Transmission & Distribution)	
Transmission and distribution grid management	• Sensor-based networks • Embedded systems and software • Integrated software systems and application programming interfaces (APIs) • Smart meters • Communications protocols, including machine-to-machine communications (M2M)
Storage	
Storage capacities (physical and logical)	• V2G, G2V and vehicle-to-home (V2H) • Smart meters • End-user interfaces
Retail	
Dynamic and real-time pricing for electricity consumption and distributed generation	• Smart meters • End-user interfaces
Electricity conservation and energy-efficiency	• End-user interfaces
Consumption	
	• Smart meters • Electricity data intelligence
(Automated) demand management	
	• End-user interfaces • Smart meters • Communications protocols, including M2M • Smart building technologies • Smart electronic devices • Data centers and cloud computing
Integration of electric vehicles (and renewable energy sources)	• End-user interfaces • Smart meters • V2G, G2V • Communications protocols, including M2M • Integrated software systems and APIs
Facilitate access to electricity in developing countries (Electrification)	

(Source: OECD, 2012)

grid infrastructures (transmission networks). Applications include Intelligent Electronic Devices (IEDs), Phasor Measurement Units (PMUs) and Supervisory Control and Data Acquisition (SCADA) systems. However, requirements for communications and data handling are expanding rapidly: the increase in market actors due to liberalisation increases the need for fast and interoperable access to electricity data (OECD, 2012).

Dispersed (renewable) energy production and storage through "private" PV-panels and G2V /

V2G / V2H models (grid 2 vehicle / vehicle to grid / vehicle to home distribution and storage models using e-car batteries as an intermediate power storage device in case of load surplus and power delivery in case of peak demand) also increases the complexity of national grids and distribution networks and requires better and faster information provision. The main ICT components in improving grid monitoring and control systems are (OECD, 2012):

- *Sensor-based networks* with sensors (which monitor various characteristics such as voltage, temperature and tension across T&D lines) and embedded software (converting sensor signals and feed them into a communications channel).
- *Integrated software systems, databases and APIs*. Software systems provide automated monitoring and control activities conducted by the sensors. Through application programming interfaces, data about the grid status can be provided to a large number of stakeholders, including individuals.
- *Smart meters* at customer premises may support two-fold grid management. They can enable improved individual control over electricity consumption and billing, and can further receive remote control signals to trigger household appliances to be automatically turned on and off.

Integration makes the difference in a Smart Grid, combining business and technical intelligence. In recent years ICT companies have developed tools for supplying advanced communications and analysis services to utilities and to some extent to individuals.

Today real-time pricing is not usually a topic, at least for private households. Prices for retail customers, however, are today largely static and billing is based on periodic meter readings. Smart meters and other end-user interfaces (e.g. web portals, mobile applications) can provide dynamic pricing information and consumers can then make choices about when they buy and when they feed electricity back into the grid. Price signals could impact private electricity consumption and thus lower peak demand. In the domain of wholesale electricity trading, large customers could decide on spot trading by making use of dynamic pricing.

A Smart Grid can be widely supported from smart meters by providing the following functions:

- Sensor for monitoring low voltage grid infrastructure
- Gateway to customer-side applications and data exchange for display and analysis on 3rd party devices. A variety of 3rd party software and hardware provides consumer information on electricity consumption. Google's PowerMeter, for example, can receive information from households equipped with smart meters by electricity suppliers Yello Strom (Germany), first:utility (United Kingdom) or SDG&E (United States) (OECD, 2012).
- Dynamic pricing. Accurate metering using smart meters and dual-way communications between the electricity provider and the customer enables dynamic pricing to encourage customers to adapt better to load variation, supporting load-shifts to reduce peak demand and enabling utilities to purchase high-priced electricity on the spot market during peak times.
- Display of consumption-related information: real-time prices, accurate use numbers and implicit environmental costs (GHG emissions), allowing customers to observe and adapt consumption behaviour.
- Accurate metering and billing. The majority of customers still pay their bills based on the utility's estimates, which are adjusted after regular readings at wider intervals (often only once a year). Smart meters allow frequent billing periods.

An advanced metering infrastructure (AMI) can be an enabler for effective peak demand management, particularly when coupled with dynamic pricing schemes and "smart" electrical appliances. Improved information about the current supply and price can help consumers to shift the timing of certain household appliances – dishwashers and washing machines, even charging electric vehicles.

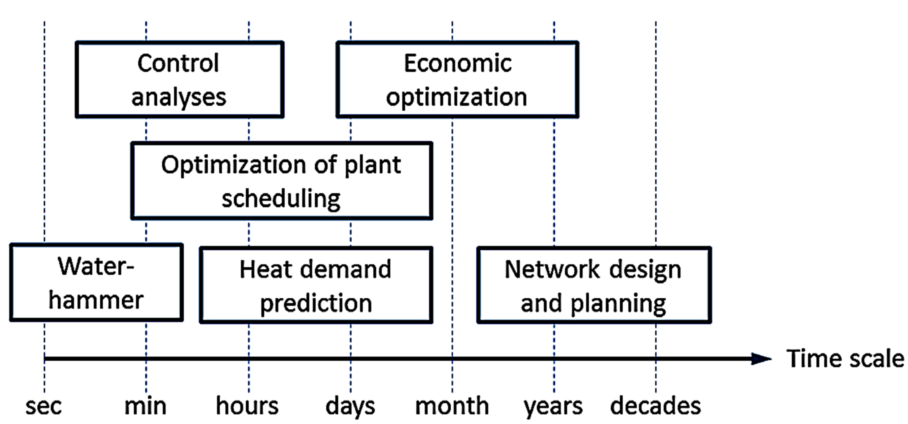
ICT SOLUTIONS FOR DISTRICT HEATING AND COOLING

Supply-side operational optimizations and network design: Depending on the scope of the analyses and the time scales to be considered (see Figure 8) there are various ICT tools available.

A number of ICT tools are available for economic and operational optimization of the scheduling of various heat generation plants in a district heating (DH) network, e.g. deco, FreeOpt, DEMS, BoFiT, ENFOR-PRESS, THERMIS, MARKAL/TIMES, MODEST, ENERGYPLAN. They perform scheduling optimization by considering the operational costs of the plants, based on fuel consumption, maintenance, CO_2-certificates, starting/stopping plant costs, forecasted potential revenue from electricity market sales in the case of CHP (combined heat and power) plants and prediction models of heat demand. To this end, DH network topology is not implemented and simplifications of distribution heat losses and pumping energy are considered. Additionally, power plant modelling is generally realised by implementing characteristic curve and production efficiencies; in only a few cases is it done using simplified physical models.

Designing DH networks requires more detailed modelling, and different network simulation environments are commercially available for this purpose, e.g. SisHyd, Sir3S, Stanet, T*SOL, EC.GIS, which are able to implement the network topology, pipe properties, pump characteristics, etc. Thus DH simulation software supports network design and subsequent network modifications (e.g. extension). However, these tools usually perform static calculations and are not able to evaluate dynamic effects, such as the water hammer (a pressure wave which occurs when a fluid in motion stops or changes direction), fluctuating energy sources (solar thermal energy, wind energy) powering heat pumps, bi-directional load flow from e.g. solar thermal panels, or micro CHP chips, or demand side management strategies. Power plant characteristics can also be implemented with more details.

Figure 8. Time considerations in district heating networks depending on the focus of the analyses
(Source: Valdimarsson, 1993)



These dynamic modelling capabilities are only offered by a few simulation tools such as Apros or libraries of the open source modelling system Modelica/Dymola allows further modelling of bi-directional load flow, part load operation of power plants, implementation of customised control strategies, integration of advanced building models for assessing demand-side management, and coupling of models from other engineering fields (e.g. assessing thermo-mechanical stresses) and the consideration of instationary effects and hydraulic phenomena.

Demand-side management for improved district heating network performance requires smart heat meters to be installed at the customer side. This makes it possible to monitor energy consumption dynamics for customers as well as for the network operator, which supports the network operator in assessing the network status, dynamic pricing and cost-related billing, more precise load forecasting and identification of problems on the customer side, e.g. high peak loads or high return temperatures.

Low return temperatures are beneficiary for district heating (DH) systems as they reduce pumping costs (reduced mass flow due to increased temperature potential) and energy losses (lower gradient to the environment) as well as increasing the usable potential of renewable sources (e.g. groundwater via heat pumps, solar thermal energy or industrial waste heat). Return temperatures can be decreased by technical modifications at the customer side (e.g. removal of installation mistakes) and by adapting customer behaviour (e.g. temperature control). Visualizing the return temperature profiles via smart heat meters enables customers to react and improve the performance of their energy system accordingly (e.g. motivated by appropriate tariff systems).

The night set-back (reduction of room temperatures during night time) is a usual measure to reduce the energy demand in buildings (Moon & Hoon, 2011). The resulting fluctuating heat consumption (high peak loads) can become a significant problem for DH network operation if heat energy to cover the fluctuation is generated by fossil fuels. Integrating additional functionalities into smart heat meters could shift heating loads to off-peak times and smooth the dynamic variation (Basciotti & Schmidt, 2013). The same also applies to district cooling.

However, since many European urban district heating networks were installed several decades ago, the general diffusion of ICT and sensors in the networks is rather low. Often, relevant data is only monitored at the supply side, at some critical network points, by larger customers and in recently installed network sections. As a consequence, the added value for introducing smart heat meters with the additional functionalities described above must be carefully calculated: suitable systems are still relatively expensive and the installation costs are high (including the setup of an appropriate communication infrastructure). Additional barriers are legal issues (e.g. data security and privacy) and a possible impact on the comfort of the customers being subject to demand-side measures. Nevertheless, for the most relevant loads in DH networks (e.g. industrial customers, large office buildings, swimming pools, hotels …) the potential for load shifting and the effect of return temperature reduction are great compared to individual single family homes; the implementation of smart heat meters could be very cost effective.

In district heating systems in future Smart Cities, ICT will gain significant importance for enabling overall analyses, control and system optimization, not only in terms of the interfaces to other energy vectors (electricity and gas, e.g. www.orpheus-project.eu) but also for related energy conversion technologies and various storage options. However, this will require the development and diffusion of open and standardised interfaces between the different networks and communication infrastructures to allow interoperability.

ICT SOLUTIONS FOR DEMAND-SIDE MANAGEMENT (DSM)

In general, electricity customers have particular consumption preferences at different times of the day resulting in diurnal consumption patterns with distinct peaks and sinks. To achieve high levels of reliability and robustness in energy supply systems, the infrastructure is designed for peak demand. To overcome these problems, different solutions have been developed to shape consumer energy consumption profiles so that power or heat generation capacity can be used more efficiently to avoid deploying additional energy generation and transmission infrastructure or purchasing peak power at high prices to supply short-term peak demand. These solutions are generally known as demand-side management (DSM), aiming to reduce or shift energy consumption to smooth consumption peaks and sinks.

The success of DSM depends on the share of the controlled total. One option in DSM is direct load control where, for example, based on an agreement between the utility company and the customer, the utility remotely controls certain appliances in a household by switching them on and off to avoid consumption during peak load time. A further option is to supply specific pricing to encourage users to individually manage their loads and reduce their own energy costs. Here we address targeted incentives, technologies and customer education programs directed towards reducing or changing patterns of energy use.

Today most individual load control decisions are made manually, which makes it difficult for the participants to monitor real-time prices and use advanced pricing methods. In fact, the lack of consumer knowledge on how to respond to time-varying prices is currently one of the main barriers to fully utilizing the benefits of real-time pricing methods and DSM in general. This problem can be resolved to some extent by equipping customers with home automation systems and implementing automated energy consumption scheduling units providing pricing information to schedule the operation of residential appliances (Samadi et al., 2011).

Thus automated DSM systems can significantly enhance the efficiency and reliability of power supply and grid operation. Applications monitoring energy supply and consumption follow the concept of SCADA systems (supervisory control and data acquisition) which monitor and control real time data – starting with single sites and ending with systems covering large areas (ranging from industrial plants to whole countries). There are various ICT solutions supporting DSM at national level, utility level and / or customer level.

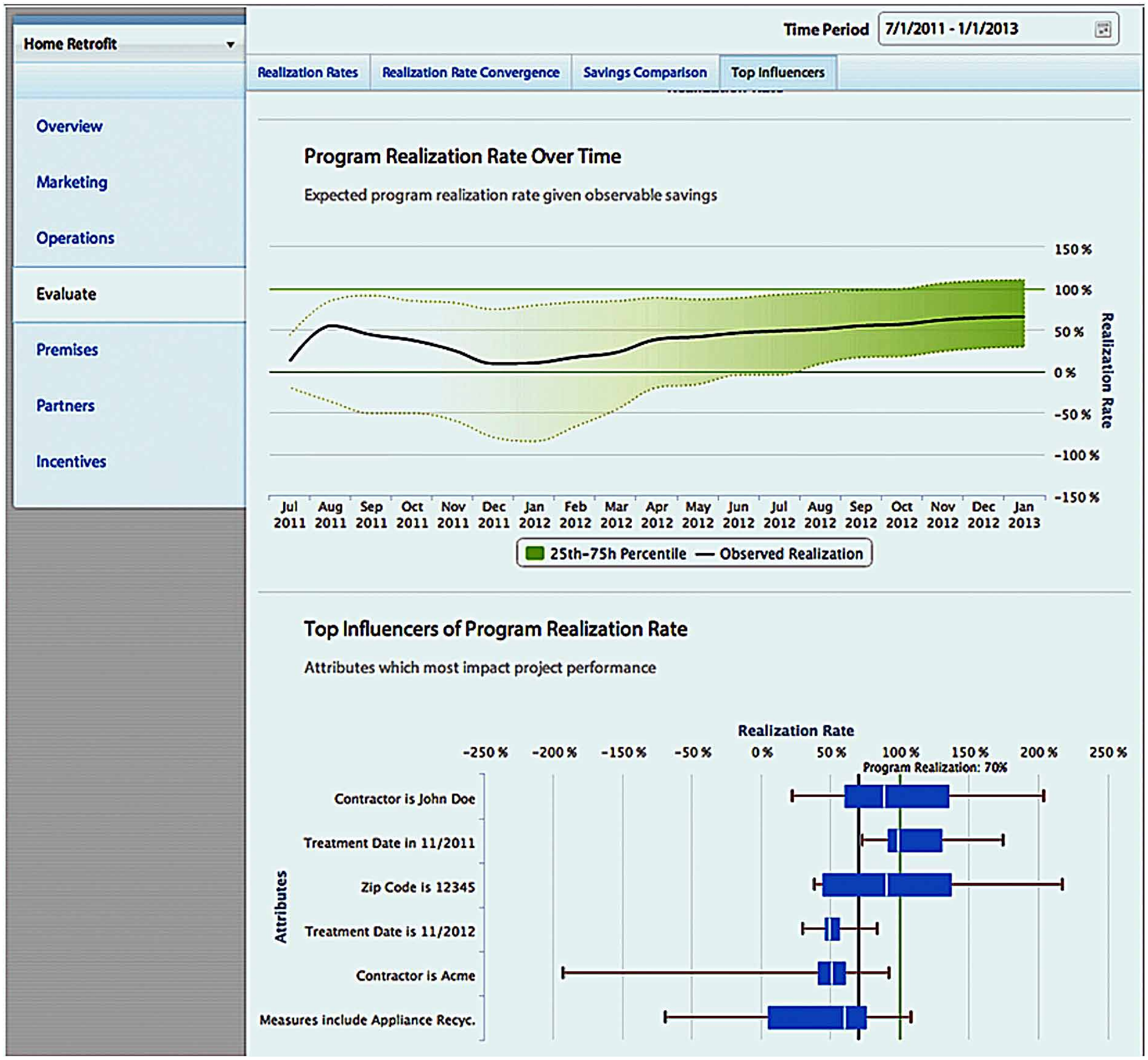
The "Optix" product line from EnergySavy is one example of demand-side management systems enabling utilities and their partners to achieve DSM goals. Not only does the energy service company (ESCO) gain an insight into consumer behaviour, but customers also learn where to start and proceed with energy efficiency as they are able to monitor their progress in energy saving. Several tools can be obtained – Optix-Engaging is the starter, providing households with a user-friendly experience, Optix-Evaluate allows real time performance analysis (see Figure 9), Optix-Manage allows results which track overall consumption for the ESCO .

ESCOs from several U.S. states and cities have applied the system to enhance state-wide or company DSM: Utah, Puget Sound Energy, New Jersey Natural Gas, Efficiency Vermont, to name a few.

ICT SOLUTIONS FOR SMART BUILDINGS: BUILDING ENERGY MANAGEMENT AND BUILDING AUTOMATION

As stated earlier, a Building Information Model (BIM) describes all the physical and functional characteristics of a single building. A BIM is conceived as a source of shared knowledge supporting

Figure 9. Screenshot from analysis results carried out by Optix-Evaluate
(Source: http://www.energysavvy.com/products/optix-evaluate/)



decision-making about a facility from its early conceptual stages, through design and construction, during its operational life and right up to its demolition. Today a number of approaches exist for BIMs to estimate the total energy demand and increase buildings' energy efficiency.

Building automation and control systems (BACS) are well-established infrastructural systems in functional buildings today. Information on the building's physics and energy systems can be used in building operation by BACS to ensure higher quality control. Building automation provides the functionality necessary to operate complex buildings and supports different domains such as heating, ventilation, air conditioning (HVAC), access control, lighting, sun blinds or fire alarms. A building automation system is a combination of information and communication technology which enables efficient and flexible building control. All relevant systems in the building are connected via a communication network, the most common being LonWorks, BACnet and KNX (Loy et al., 2001; Merz et al., 2009). With its sensors, actuators, communication networks and computing resources, a BACS is the perfect platform enabling the building to become a service provider for a Smart City with respect to energy demand control. Building automation saves energy during operation. European standard EN 15232 (CEN, 2012) defines different energy efficiency classes for building automation and control systems. In heating control, for example, building automation can have no automatic control (class D), outside temperature compensated control (class C, the reference class), indoor temperature of distribution network water temperature (class B) or additionally have a total interlock between heating and cooling control (class A). A building management system that fulfils the requirements of class A (not only in heating, but also in lighting, HVAC and sun blinds) has an efficiency factor of 0.7. (The efficiency factor, defined by European standard EN 15232, indicates the ratio of the achieved efficiency compared to the reference class C efficiency, which has a factor of 1). EN 15232 uses only state-of-the-art technology to increase energy efficiency with IT methods. But the strength of building automation systems is their versatility: the building automation infrastructure can be used for different applications simultaneously, creating synergies between them. A development in this direction is demand-side management in buildings: buildings, and especially the HVAC systems in the building, can operate in a way that does not affect user comfort, but makes it possible to adapt the electric consumption profile over the day. This flexibility can be used to better integrate volatile renewables such as photovoltaic systems or wind power. A BACS that can modify demand based on available renewable energy increases on-site usage of energy, reducing the amount of energy that needs to be transported via the electric grid and thus reducing transport losses.

From the perspective of a Smart City, it is not easy to address individual buildings through simulation systems taking into account a range of 1,000 to several 10,000 or even 100,000 households. This is, however, necessary, if energy management is envisioned at city level. Currently buildings and their embedded households and flats are island systems that do not provide standardized communication interfaces to the smart infrastructure. Much effort is put into possibilities for influencing building operation with goals from the "outside". The building automation market is still fragmented and common, standardized solutions have yet to penetrate the market. City-level demand-side management (DSM) strongly requires this access, but this requires a change in the way a building automation system is conceived. Currently the first instance is supervisory control, responsible for overall control of the building and for providing a user interface for the building operator. Traditionally, an instance above supervisory control has not been provided for. With the introduction of Enterprise Resource Planning (ERP) tools this has become more common, but it is still vendor-specific in a fragmented market. A building consists of many components which are connected into a system – the building. Still, the building is just one component of a bigger system – the city. Once it is understood that systems are only components of bigger systems, the building can become an active participant in a Smart City.

SOLUTIONS AND RECOMMENDATIONS

ICT is one of the main enabling technologies for Smart Cities. However, the selection of target-oriented and cost-effective equipment will be one of the main challenges in the future.

The examples described above may differ in scale or approach, but they all present some common traits that will be summarised in the following section. First and foremost: ICT-based tools are closely connected to the goals to be achieved when speaking of Smart Cities. The focus is indeed both on modelling approaches and data integration.

Regarding the former, a number of solutions already exist today, ranging from the more "classical" top-down approaches, especially at city-level, to the more specific bottom-up ones. Which approaches and tools to adopt depends of course on a number of conditions, but the amount and quality of available data play major roles. An important step is the slow but progressive switch from simple qualitative analyses to precise, quantitatively and spatially defined ones. Information, at any level, must not only be known in detail, but must also show a precise spatial reference.

Given the multiplicity of system elements and energy topics to be dealt with, the availability of a common set of data to be shared among stakeholders in the planning process is of great importance. A consistent, detailed data repository is required to avoid errors, ease management and enhance cost-effectiveness for scenario development. Quite some effort is therefore necessary for the exploration, collection, error check and integration of the heterogeneous data sources required to describe cities. Data integration can drain huge quantities of resources (in terms of time and money) when a simulation and assessment framework needs to be established for a city. If original data are not available, proxy data must be made available, allowing a workaround for modelling and assessment. These are necessary steps which, once carried out, finally result in reducing the overall effort for many future repetitions of simulation, analysis and assessment.

The adoption of 3D city models has recently started, showing the potentials and strengths such tools may offer. 3D city models will be further exploited as they allow the inclusion of many relevant entities and aspects of a city and can act as a model framework for all energy-relevant aspects within a city. If Smart Cities are supposed to deal with complex topics in a holistic way, then 3D city models are (one of) the right approaches to choose.

When supporting urban energy planning in an integrated way, different resolutions must be incorporated regarding space, time and spatial dimensions (3D). An ideal final state of an integrated urban energy planning tool for monitoring and maintaining urban energy systems may cover the following topics:

- Real time monitoring of energy consumption by energy carrier for the entire city, certain districts, selected blocks or even buildings,
- Control of the systems including distribution network connections and the appliances of a household connected to the grid in case of emergency or as routine,
- Assessment of consumption by energy carrier, consumer groups and/or appliance groups and related key performance indicators to evaluate progress on energy efficiency, renewable energy use share, greenhouse gas mitigation performance,
- Decision support for energy consumption improvement measures allowing *ex ante* assessment of the impact of adaptation scenarios for the entire city or for selected areas addressing districts, blocks or selected groups of buildings or individual buildings, which finally will turn out as hot spots in need of quality improvement,
- Decision support for urban development, analysing energy supply alternatives to identify the most sustainable and cost effective solutions.

FUTURE RESEARCH DIRECTIONS

Further research is needed for software and hardware solutions in order to make continuous progress in developing fully integrated systems which span the range of different temporal and spatial resolutions. As all single functionalities describing the system entities and the processes are developed, research resources must be concentrated on the dynamic scalability of such a system.

Enabling bi-directional Building-to-Grid connections (buildings demanding energy from the grid but also delivering energy into the grid) requires an IT-framework which allows electric profile control of buildings according to the needs of a Smart Grid, e.g. supporting smooth consumption peaks by delivering electricity from local PV panels into the grid.

Here we see the same maturity of methodology development. Most of the required information and communication technology is already in place: buildings can communicate and control the building system, do the necessary calculations and store data for later analysis. Nevertheless two main developments are required before smart buildings can become fully integrated into a Smart Grid and a Smart City. The first involves integrating advanced ICT methods into building automation; the second covers the need for open (and possibly standardized) systems. Advanced ICT methods summarize developments in other domains that might benefit smart buildings.

On-site electricity generation and storage models (distributed power generation through private PV panels, and related G2V/V2G/V2H models – see Table 1) make consumers become *prosumers* capable of changing their role in the market. Technological innovation and business models will go hand-in-hand here (Kanchev et al., 2011).Various countries are leading Smart Grid development, while others do not yet have a market as they lack common regulations for flexible consumer/prosumer behaviour in an energy grid (Brandstatt et al., 2012).

The usage of ICT and information fusion for smart and grid-friendly buildings can be categorized as follows:

- *Energy efficiency*: tools such as sensor networks, remote (consumption) data acquisition and data mining can be used to show correlations between expensive and emission-prone consumption peaks and operational data and benchmark the building against others (e.g. kWh per employee and year). At present, consumption figures are yearly aggregates and they do not provide much information. ICT is currently changing this, feeding energy information further up the line into enterprise resource planning tools and accounting software.
- *Consumption dynamics*: As the behaviour of buildings slowly leaves behind the statistical patterns of the last 100 years (due to on-site photovoltaic systems, response to dynamic prices, etc.), established methods are failing to consider their dynamics in grid management. At the same time, intelligent buildings offer some degrees of freedom that were unexploited up to now. Combining both leads to buildings that cooperate with other distributed energy resources in the grid. The ICT interfaces and protocols are far from being standardized and established. See Palensky and Kupzog (2013) for an overview of related Smart Grid topics and their ICT aspects.

Two examples are given below:

1. The first example addresses the predictability of building behaviour as a response to framework conditions in the near future, in order to properly exploit flexibility in building operation: How will outside temperatures and indoor occupancy influence energy usage? How much will the volatile renewable energy source produce?

This information is needed to establish predictive control of the energy systems and to optimize operations. The according algorithms are used today in industrial processes known as model-based predictive control.

2. The second example is the optimization of building operations by analyzing and understanding the recorded operation data. Building automation data records can help identify inefficient operation, but require methods and algorithms found today in data mining applications. Open systems provide interoperability and open software standards which allow us to learn from other buildings' behaviour with respect to certain building and framework conditions.

While building automation uses a set of communication protocols to standardize interaction between the components, there are currently no established standards for accessing building management systems from outside or defining services that could be used from outside (e. g. the flexible service for Demand-Side Management). Current building management systems are proprietary, closed systems that were not designed to interoperate on this level. Before buildings can be integrated into a large scale, city-wide operation and optimization, it is necessary to agree on standardized and open system definitions.

CONCLUSION

Given the complexity of a city, including multiple energy (sub)-systems that are linked to different spatial and temporal scales, ICT solutions must be able to integrate these different scales, but also to cope with the demand and supply side at the same time.

Any energy-related urban planning action is today confronted with several, sometimes concurrent, challenges and decisions. These include the selection of different types of energy generation and distribution technologies, the construction and extension of supply and utility infrastructures and an overall increase in energy efficiency, as well as the need to simulate different scenarios according to different energy policies to assess the impact of the measures. ICT tools can therefore help with the holistic approach needed to tackle these challenges. First of all, problems can be analysed and given a quantitative answer, with different levels of accuracy depending on the level of detail considered.

Nowadays, precise information about all physical and functional characteristics of a single (modern) building can be organised, simulated and stored. Moving from the single-building dimension to the urban one can be achieved by means of different strategies, depending on the amount and accuracy of available data. The adoption of virtual 3D city models can be seen as a major step toward data integration and harmonisation, and, although the resources-intensive step of data integration is still required, the emergence of new tools is making the task easier. Even the move from 2D to 3D allows for more possibilities to extract data automatically (e.g. computation of shared walls or volumes).

In the near future, the goal is to formally define and create an integrated and coherent platform aimed at decision support for urban energy performance improvement and related impact assessment. This platform should be based, among others, on semantically enriched 3D virtual city models (which will serve as data hubs for all city-relevant simulation tools), being able to deal with the interactions between energy demand, supply, networks and storage, taking into account the scales, from (sub)-building level to blocks, neighbourhoods, districts and finally the entire city. Additionally, it must be possible to integrate different temporal scales (ranging from minute time slices to annual totals) to allow system loads to be balanced by simulating, monitoring and controlling the energy demand and supply state – the latter by integrating dispersed power generation through "private" PV-panels and integrated power delivery/storage/consumption models (G2V / V2G / V2H) to head off load surplus and shortage through demand fluctuation).

Thus the final goal for maintaining and improving Smart Urban Energy Systems is to strengthen the applicability of models and tools with respect to:

- Integrating observation, control, simulation and assessment of centralized and distributed energy supply systems,
- Integrating energy supply and demand side control at individual and aggregated levels – from individual household demand and building modelling to city wide demand / supply modelling, control, observation and assessment,
- Simulating real-time system behaviour which allows spatial as well as temporal aggregation of supply, storage and demand.

REFERENCES

Acatech. (2012). *Future Energy Grid-Migration to the Internet of Energy*. Munich, Germany: National Academy of Science and Engineering.

Agugiaro, G. (2014). From sub-optimal datasets to a CityGML-compliant 3D city model: experiences from Trento, Italy. In Proceedings of International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (vol. XL-4, pp. 7-13).

Agugiaro, G., Nex, F., Remondino, F., De Filippi, R., Droghetti, S., & Furlanello, C. (2012). Solar radiation estimation on building roofs and web-based solar cadaster. In Proceedings of Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (vol. I-2, pp. 177-182).

Basciotti, D., & Schmidt, R.R. (2013). *Demand side management in District heating networks, Simulation case study on load shifting*.

Becker, T., Nagel, C., & Kolbe, T. H. (2013). *Semantic 3D modeling of multi-utility networks in cities for analysis and 3D visualization. Progress and New Trends in 3D Geoinformation Sciences* (pp. 41–62). Berlin, Heidelberg: Springer Verlag. doi:10.1007/978-3-642-29793-9_3

Boyd, S., & Chan, R. (2002). *Placemaking: tools for community action*. Retrieved June 09, 2014, from http://www.sustainable.org/images/stories/pdf/Placemaking_v1.pdf

Brandstatt, C., Friedrichsen, N., Meyer, R., & Palovic, M. (2012). Roles and responsibilities in smart grids: A country comparison. In *Proceedings of IEEE International Conference on the European Energy Market* (pp. 1-8). doi:10.1109/EEM.2012.6254698

Carrión, D., Lorenz, A., & Kolbe, T. H. (2010). Estimation of the energetic rehabilitation state of buildings for the city of Berlin using a 3D City Model represented in CityGML. *International Conference on 3D Geo-Information.*

CEN-CENELEC-ETSI Smart Grid Coordination Group. (2012). *Smart Grid Reference Architecture.*

CEN/European Committee for Standardisation. (2012). *EN 15232 Energy performance of buildings - Impact of Building Automation*. Controls and Building Management.

Connolly, D., Lund, H., Mathiesen, B. V., & Leahy, M. (2010). A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, *87*(4), 1059–1082. doi:10.1016/j.apenergy.2009.09.026

Girardin, L., Marechal, F., Dubuis, M., Calame-Darbellay, N., & Favrat, D. (2010). EnerGis: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas. *Energy*, *35*(2), 830–840. doi:10.1016/j.energy.2009.08.018

Gnüchtel, S., & Groß, S. (2010). Free optimization tools for district heating systems. In *Proceedings of International Symposium on District Heating and Cooling*.

International Energy Agency. (2011). *Smart Grids Roadmap*. Retrieved June 09, 2014, from http://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

Kaden, R., & Kolbe, T. H. (2013). City-wide total energy demand estimation of buildings using Semantic 3D city models and statistical data. In Proceedings of Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (vol. II-2/W1).

Kanchev, H., Di, L., Colas, F., Lazarov, V., & Francois, B. (2011). Energy Management and Operational Planning of a Microgrid with a PV-Based Active Generator for Smart Grid Applications. *IEEE Transactions on Industrial Electronics*, *58*(10), 4583–4592. doi:10.1109/TIE.2011.2119451

Keirstead, J. (2011). *Types of urban energy system models*. Retrieved June 05, 2014, from http://www.jameskeirstead.ca/blog/types-of-urban-energy-system-models/

Keirstead, J., Samsatli, N., & Shah, N. (2009). SynCity: an integrated tool kit for urban energy systems modelling. In *Proceedings of Urban Research Symposium*.

Kjems, E., & Wen, W. (2011). A 3D city model used as user-interface for an energy-system. In *Proceedings of International Conference on Computers in Urban Planning and Urban Management* (pp. 37-46).

Kolbe, T. H. (2009). *Representing and exchanging 3D city models with CityGML. 3D geo-information sciences* (pp. 15–31). Berlin: Springer. doi:10.1007/978-3-540-87395-2_2

Krüger, A., & Kolbe, T. H. (2012). Building analysis for urban energy planning using key indicators on virtual 3D city models - the Energy Atlas of Berlin. In *Proceedings of Archives of the Photogrammetry* (Vol. 39, pp. 1–25). Remote Sensing and Spatial Information Sciences.

Loibl, W., Vielguth, S., Peters-Anders, J., Möller, S., Jakutyte-Walangitang, D., Brinkman, J., . . . Fumarola, M. (2014). The TRANSFORM DSE - an interactive decision support environment for serving smart city strategy-development and local measure implementation. In Proceedings of Real Corp (pp. 711-720).

Loy, D., Dietrich, D., & Schweinzer, H.-J. (2001). *Open control networks: LonWorks/EIA 709 technology*. New York: Springer. doi:10.1007/978-1-4615-1475-6

Merz, H., Backer, J., Moser, V., Hansemann, T., Greefe, L., & Hübner, C. (2009). *Building Automation: Communication Systems with EIB/KNX, LON and BACnet*. New York: Springer. doi:10.1007/978-3-540-88829-1

Metrex. (2014). *ReMAC Planung für Energie*. Retrieved June 05, 2014, from http://www.regenerative-energy.org/DE/metrex.php

Moon, J. W., & Hoon, H. S. (2011). Thermostat strategies impact on energy consumption in residential buildings. *Energy and Building*, *43*(2-3), 338–346. doi:10.1016/j.enbuild.2010.09.024

OECD. (2012). *ICT Applications for the Smart Grid: Opportunities and Policy Implications*. Retrieved May 31, 2014, from10.1787/5k9h2q8v9bln-en

Palensky, P., & Kupzog, F. (2013). Smart Grids. *Annual Review of Environment and Resources*, *38*(1), 201–226. doi:10.1146/annurev-environ-031312-102947

Parish, Y. I. H., & Müller, P. (2001). Procedural Modeling of Cities. In *Proceedings of the 28th annual conference on Computer graphics and interactive techniques* (pp. 301-308).

Robinson, D., Haldi, F., Kämpf, J., Leroux, P., Perez, P., Rasheed, A., & Wilke, U. (2009). CitySim: Comprehensive micro-simulation of resource flows for sustainable urban planning. In *Proceedings of International IBPSA Conference*.

Samadi, P., Wong, V. S. V., Schober, R., & Mohsenian-Rad, H. (2011). The Role of Demand Side management. Retrieved June 06, 2014, from http://smartgrid.ieee.org/october-2011/418-the-role-of-demand-side-management

Strzalka, A., Bogdahn, J., Coors, V., & Eicker, U. (2011). 3D City modeling for urban scale heating energy demand forecasting. *HVAC&R Research, 17*(4), 526–539.

Tommis, M., & Decorme, R. (2013). *ICT Roadmap for Energy Efficient Neighbourhoods*. Retrieved May 03, 2014, from http://www.ireenproject.eu/wp-content/uploads/2011/11/eChallenges2012_fullpaper_final.pdf

Valdimarsson, P. (1993). *Modelling of geothermal district heating systems*. (Doctoral dissertation). University of Iceland, Rejkavik.

Waddell, P. (2000). A behavioral simulation model for metropolitan policy analysis and planning: Residential location and housing market components of UrbanSim. *Environment and Planning. B, Planning & Design*, *27*(2), 247–263. doi:10.1068/b2627

ADDITIONAL READING

Azuma, R. (1997). A Survey of Augmented Reality Presence. In *Proceedings of Presence* (pp. 355–385). Teleoperators and Virtual Environments.

Bahar, Y. N., Pere, C., Landrieu, J., & Nicolle, C. (2013). A Thermal Simulation Tool for Building and Its Interoperability through the Building Information Modeling (BIM) Platform. *Buildings*, *3*(2), 380–398. doi:10.3390/buildings3020380

Caperna, A. (2010). Integrating ICT into Sustainable Local Policies. Handbook of Research on E-Planning: ICTs for Urban Development and Monitoring. Hershey: New York.

Darby, S. (2009). Smart metering: What potential for householder engagement? *Building Research and Information*, *38*(5), 442–457. doi:10.1080/09613218.2010.492660

Dietrich, D., Bruckner, D., Zucker, F., & Palensky, P. (2010). Communication and computation in buildings: A short introduction and overview. *IEEE Transactions on Industrial Electronics*, *57*(11), 3577–3584. doi:10.1109/TIE.2010.2046570

European Commission. (2010). *Energy 2020 - A strategy for competitive, sustainable and secure Energy*. Retrieved May 06, 2014, from http://ec.europa.eu/energy/publications/doc/2011_energy2020_en.pdf

Ferhatbegovic, T., Zucker, G., & Palensky, P. (2011). Model based predictive control for a solar-thermal system. In *Proceedings of IEEE AFRICON* (pp. 1-6). doi:10.1109/AFRCON.2011.6071992

Greenpeace. (2010). *How dirty is your data? A look at the energy choices that power cloud computing*. Retrieved May 31, 2014, from http://www.greenpeace.org/international/Global/international/publications/climate/2011/Cool%20IT/dirty-data-report-greenpeace.pdf

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2011). Smart Grid Technologies: Communication Technologies and Standards. *IEEE Transactions Industrial Informatics*, *7*(4), 529–539. doi:10.1109/TII.2011.2166794

International Energy Agency. (2009). *Prospects for large-scale energy storage in decarbonised power grids*. Retrieved May 31, 2014, from http://www.iea.org/publications/freepublications/publication/energy_storage.pdf

International Energy Agency. (2010). *Energy Technology Perspectives 2010. Scenarios and strategies to 2050*. Retrieved May 31, 2014, from http://www.iea.org/publications/freepublications/publication/etp2010.pdf

International Energy Agency. (2010). *World Energy Outlook 2010.* Retrieved May 31, 2014, from http://www.worldenergyoutlook.org/media/weo2010.pdf

Keirstead, J., & Shah, N. (2013). *Urban Energy Systems: An Integrated Approach*. Oxon: Routledge.

Leal, S., Dubisch, F., Stift, F., Zucker, G., & Palensky, P. (2013). Semi-automated deployment of Simulation-aided Building Controls. In *Proceedings of Annual Conference of the IEEE Industrial Electronics Society* (pp. 5747-5754).

Palensky, P., Zucker, G., Judex, F., Braun, R., Kupzog, F., Gamauf, T., & Haase, J. (2011). Demand Response with Functional Buildings using simplified Process Models. In *Proceedings of Annual Conference of the IEEE Industrial Electronics Society* (pp. 3113-3118). doi:10.1109/IECON.2011.6119828

Pol, O., Palensky, P., Kuh, D., Leutgöb, K., Page, J., & Zucker, G. (2012). Integration of centralized energy monitoring specifications into the planning process of a new urban development area: a step towards smart cities. *e & i Elektrotechnik und Informationstechnik, 129*(4), 258-264.

Silva, C. N. (Ed.). (2010). *Handbook of Research on E-Planning: ICTs for Urban Development and Monitoring*. Hershey, PA: IGI-Global. doi:10.4018/978-1-61520-929-3

Soucek, S., & Zucker, G. (2012). Current developments and challenges in building automation. *e & i Elektrotechnik und Informationstechnik, 129*(4), 278-285.

Stadler, A., & Kolbe, T. H. (2007). Spatio-semantic coherence in the integration of 3D city models. In *Proceedings of International ISPRS Symposium on Spatial Data Quality* (pp. 13-15).

United States Federal Energy Regulatory Commission. (2009). *A national assessment of demand response potenti*al. Retrieved May 31, 2014, from http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf

Waddell, P. (2011). Integrated Land Use and Transportation Planning and Modeling: Addressing Challenges in Research and Practice. *Transport Reviews*, *31*(2), 209–229. doi:10.1080/01441647.2010.525671

Waddell, P. (2013). *Draft Technical Documentation: San Francisco Bay Area, UrbanSim Application*. Retrieved May 06, 2014, from http://iurd.berkeley.edu/research/2013_04_01_DRAFT_RELEASE_UrbanSim_Documentation.pdf

Waddell, P., ... (2011). The Open Platform for Urban Simulation and UrbanSim Version 4.3. Users Guide and Reference Manual. University of California Berkeley and University of Washington. Retrieved May 31, 2014, from http://www.urbansim.org/downloads/manual/dev-version/opus-userguide/

Zarli, A., & Regzui, Y. (2013). ICT for energy-efficient urban communities: the IREEN roadmap and the case of a developing city. Retrieved May 31, 2014, from http://www.ireenproject.eu/wp-content/uploads/2013/12/Manuscript-Zarli-Rezgui-CIBW78-2013-180713-final.pdf

Zucker, G., Palensky, P., Judex, F., Hettfleisch, C., Schmidt, R.-R., & Basciotti, D. (2012). Energy aware building automation enables Smart Grid-friendly buildings. *e & i Elektrotechnik und Informationstechnik, 129*(4), 271-277.

KEY TERMS AND DEFINITIONS:

Building Automation: ICT-based control of the energy performance of buildings with respect to security, fire and flood safety, lighting, shading, heating, cooling, humidity control and ventilation.

Decision Support Tool: ICT-based tool supporting decision making through simulating the implementation of probable measures and assessing the resulting effects.

Demand-Side Management: Control of the individual energy demand and observation of the individual and aggregated energy demand.

District Heating and Cooling: This is a technological concept comprising infrastructure for delivering heating and cooling services to distributed customers. It is mainly based on a wide range of local (fossil but renewable) energy sources that under normal circumstances would be difficult to use or remain unused (e.g. CHP (combined heat and power plants), geothermal, large-scale solar thermal or ambient energy (via heat pumps) and industrial waste heat). The energy source may change over time as the energy market and technologies change to favor new generation technologies or other more economic sources.

Energy Policy Assessment: Assessment of the effectiveness of energy policy decisions with respect to effects on (fossil) energy demand reduction, greenhouse gas emission mitigation, increases in renewable energy usage and further (positive or negative) socio-economic and environmental development.

Energy Supply Management: Monitoring, assessment and control of the energy supply, currently considering the integration of distributed (renewable) energy sources.

GIS, Geographic Information System: Software designed to manage, manipulate, analyze and present spatial or geographical data. Spatial data represent geo-located, spatial objects (areas, points, lines, raster cell sets, recently also 3D-objects) with thematic attributes describing the objects' properties) building together a digital map. They are stored either in file sets with files containing geometric features and a file containing attributes – linked to these geometric features, or they are stored in geodatabase systems with collections of digital maps. GIS-applications allow users to create interactive queries, to analyze spatial information, to edit geometric data, to generate new content through geometric functionalities (e.g. intersecting maps, calculating spatial averages, sums, etc., calculating new attribute content) and to present the results of all these operations.

Smart Grid: The extension of a power grid system from a unidirectional system of electric power generation, transmission, electricity distribution, and demand-driven control to a bidirectional system enabling distributed power generation and supply providing continuous information on the system state by means of digital processing and communication, making data flow and information management a central feature.

Urban Development Simulation: Modelling of (spatial) urban development processes over time by simulating individual actors' decisions resulting in change of land use, land use density and spatial interaction as well as changes in urban metabolism (energy consumption, emissions, waste, wastewater) through land-use related activities, some of them listed in the energy planning tool description.

Urban Energy Planning Tool: ICT-based tool which allows spatially-explicit assessment of energy efficiency improvement potentials and energy demand and supply modeling through activities triggering energy consumption (heating, cooling, lighting, mobility) and energy generation. The spatial explicitness refers to different spatial scales ranging from building to block, neighborhood and city level and to the visualisation of model results in maps and 3D renderings.

Chapter 9
Electronic and ICT Solutions for Smart Buildings and Urban Areas

Luca Tamburini
University of Trento, Italy

Maurizio Rossi
University of Trento, Italy

Davide Brunelli
University of Trento, Italy

ABSTRACT

Nowadays, residential hybrid energy systems are moving from being a pure theoretical exercise to real applications for new urban areas. The growing interest related to the needs of reducing pollution, the phasing out of fossil fuel resources and the need to safeguard the environment, have led to a large number of studies and solutions to reduce fuel consumption and to manage energy sources in a better way, leading to an innovative concept of the city where smart infrastructures are in place. In this chapter we introduce the concept of hybrid energy systems, namely buildings that can exploit both renewable energy sources and the grid. On top of it, a system manager schedules the usage of electrical appliances to minimize the electricity bill while providing peak shaving and load balancing services to utilities and service providers.

INTRODUCTION

A city becomes *smart* whenever investments in ICT referred to human and social capital ensure sustainable economic progress, a high quality of life and an efficient management of natural resources (Seisdedos, 2012). Indeed, with the term *smart city* we define a set of urban planning strategies aimed at optimizing and innovating public services in such a way as to connect infrastructures with human/intellectual/social capital. This result can be achieved thanks to new communication technologies, mobility innovations and environmental safeguards/energy efficiency:

DOI: 10.4018/978-1-4666-8282-5.ch009

the common objective is to improve the quality of life, satisfying the needs of citizens, businesses and institutions. A marked line between *smart cities* and *digital cities* can be defined, due to the profound difference between a city which leverages on environmental & social capital and a city with a huge technological infrastructure. Urban performances are not only measured with the pure presence of infrastructures, but also with the availability and quality of communication, knowledge and social infrastructures which determine urban competitiveness.

The expression *Smart city* is frequently used in different contexts. In economics, it describes *smart* industry, and especially industries related to ICTs in different forms. Moreover, *smart city* can be used in regard to the education of its inhabitants: a *smart city* definitely has *smart* citizens. In other cases it can be referred to associate governments, administrations and their citizens: "e-governance" and "e-democracy" are increasingly popular and widely-used terms these days. Furthermore, *smart city* is associated with modern transport technologies, i.e. *smart* systems capable of improving urban traffic and mobility. Finally, aspects related to quality of life are often associated with the word *smart*, in connection to sustainability, green energy and security in general terms. Above all, the level of innovation and problem-solving capabilities define *smart cities*: ICT technologies are the most important means of improving these characteristics. In this way, *smartness* is somehow an internal quality of a place, city or region in which innovation processes are simplified through information and communication technologies. The *smartness* level is mainly defined according to people, cooperation systems, digital infrastructures and the means provided by the community to citizens.

In this context, a pillar infrastructure of a *smart city* is the power distribution grid. When power distribution infrastructures exploit ICT for improving overall efficiency and sustainability, we can refer to them as fundamental components in the larger domain, better known as *Smart Grids*.

Smart cities and *smart grids* are strictly correlated: the majority of existing *smart cities* can leverage on s*mart grid technologies*, including mostly energy-oriented objectives. While *smart cities* can make the user aware of energy efficiency and savings, *smart grid* components provide infrastructures capable of connecting different elements of the city itself.

A *smar*t *grid* is based on a concept of bi-directional electricity flow where buildings can also generate and store electric energy, while some years ago they were simply supposed to be consumers. Now, the local generation of electric power could potentially transform households into energy producers and hybrid electrical residential systems could become a source of earnings and not only used for saving money. A *smart grid* must facilitate the optimal management of the load (offering demand-side management and other ancillary services), exploiting the information processed from the meter, and should avoid energy waste, overload and voltage drops.

Moreover, *smart grids* impact positively on single user premises: home environments, in the majority of the world, are isolated energy-consuming units lacking in sustainability and efficiency. Now, in a *smart city, intelligent grids can interact directly with the end users in their dwellings,* contributing to saving energy and to using it in a more efficient way. In such a vision, s*mart houses* can be considered as active elements of a s*mart grid* (Gungor et al., 2012). A s*mart house* (Ricquebourg et al., 2006) can be considered as a residential building equipped with devices (such as *smart* meters or *smart* energy controllers) which are coordinated to achieve a common set of goals for the end users. Communication and metering/measuring technologies are crucial in this kind of scenario, making it possible to achieve the best results in terms of energy management with a strong and flexible communication network and an adequate amount of information involved.

Moreover, given that a *smart house* is inserted in the context of the *smart city*, exploiting the *smart grid* infrastructure the customer becomes part of a network with bidirectional energy flows. Indeed, green-energy intakes permit to develop and to use tools to reduce grid power demand when wind or solar power can supply the total demand. Accordingly to previous works on renewables, energy storage technologies are usually considered to store exceeding energy. Unfortunately, their cost is still a problem, and consequently their usage and sizing must be really accurate.

Green-energy technologies and smart energy management must also control techniques and algorithms to further reduce the overload, like peak clipping, load shaping and scheduling.

In particular, the scheduling of the electrical loads can arrange activities/loads at fixed intervals, satisfying constraints and a defined objective function: the algorithm will work to obtain an optimal plan according to the goals of the whole smart city. Recursively, each user at bottom level can tune it based on their specific needs, to let the network achieve the global goals.

In this huge system, the grid is responsible for power transmission and energy efficiency: these are the target variables of the scheduling problem under analysis. In particular, in this chapter we discuss the implementation for a single dwelling. The results can easily be scaled up to the size of the smart city to get an idea of the possible advantages.

BACKGROUND

Smart Grids need an interdisciplinary approach because different technologies contribute to implementing new services. For example, intelligent controls, renewable energy systems and real-time measuring are components which create the *Smart Grid* real architecture. They can be grouped in domain areas, as suggested by (Momoh, 2012), as follows:

- Renewable energy systems, which generally consist of photovoltaic systems or wind turbine elements.
- Storage systems, which are used as a buffer to temporarily “park” excess green energy from renewable sources and to compensate for their high variability.
- Transmission system, which has to deliver the energy if the players in the grid are far from each other (e.g. if renewables are not installed in the same building that consumes the energy). It ensures performance, reliability and quality of service.
- Monitoring and Control technologies, which are essential in a *Smart Grid* because it has to be capable of “self-monitoring” and “self-healing”, and must be robust to instability and to frequent variations in energy flows.
- Distribution system, which acts at the final stage of the power dispatch to end users. It can exploit *smart* meters and communication protocols to automate the process, including self-learning capabilities for automated billing, voltage and load transfer optimization and real-time pricing.

In conclusion, the coordination of the components of a *smart grid* is fundamental to improve efficiency and to facilitate the use of intelligence and energy efficient policies, also inside houses (*smart homes*). From “Inside the *Smart* Home”, by Frances K. Aldrich (2003)

A “smart home” can be defined as a residence equipped with computing and information technology which anticipates and responds to the needs of the occupant, working to promote their comfort, *convenience, security and entertainment through the management of technology within the home connection to the world beyond.*

"*Responding to the needs of the occupant*" is a fundamental goal in a *smart city*, where citizens are both active players and end users. To achieve these kinds of results (comfort, convenience, security and entertainment) the *smart* system governing the different entities in the *smart city* has to be up to date and flexible.

The adopted solutions are systems capable of exploiting energy intakes from renewables using storage systems as energy buffers, and are usually assisted by an ad hoc controller to guarantee the optimal management of energy flows. Of course, home networking is fundamental to achieving this goal, and some issues and obstacles are present, so far. For example, the *lack of a common and standard protocol* is a problem for the interoperability between different components. *High startup costs* can be a barrier for the end user, because they are still relatively high and do not encourage investments. Along with this, suppliers avoid selling products that won't be bought by consumers: in this way, the adoption of innovative technologies isn't promoted and speeded up. Finally, the *absence of general attention on the topic* is still remarkable. However, the awareness of energy costs and the trend of "going green" are expected to be accelerators for *smart* home technologies.

With a controller installed in any building, energy management policies can be defined both at urban area level and at a single building. In particular, it is possible to adopt a top-down approach, where each urban district can forecast the energy expenditure and the cost of the energy from the grid, as well as determine a budget for each single building. At the bottom level, the *Energy Manager* will determine a plan (or a schedule) of the energy usage within a specific period (e.g. 24h). In this way, shortages of energy are reduced because, for example, a single user could receive energy intakes from another user's photovoltaic system and, in addition, the wasting of excess energy when the demand is low, or unsuitable behaviors, are prevented.

This top-down approach is possible by means of measuring and communication technologies: these systems are essential in developing the *smart* network, connecting the different entities, allowing the management of the energy flow in every direction. These are now introduced, before addressing the problem of load scheduling.

Measuring Technologies

Smart meters are advanced measurement devices capable of obtaining information from loads included in a network and measuring their energy consumption, information useful for efficient monitoring and better billing. The major advantages of *smart* meters, defined as advanced metering infrastructure (AMI), are their ability to execute a large number of functions, two-way communication (both to supplier and to other meters), and the collection and storage of real-time energy consumption data. In addition, some advanced products can control loads and perform complex analysis and processing to assess the power quality of the grid and the characteristics of the loads. Figure 1 shows an example of such devices (Wispes, 2010). These are non-invasive wireless power meters with self-sustainable capability. They exploit a small clamp-on current sensor to measure current, avoiding wire cutting or circuit interruption. The energy harvesting feature permits self-sustained operations, and thus can continue to log data also without batteries. The meter can measure a 10W-10kW input power range with a 1W-5W resolution and a $\pm 1\%$ maximum measurement error. They can provide an analysis of the power quality with on-board harmonic evaluation (up to the 7th harmonic component) and wireless connectivity.

These counters have various advantages for energy suppliers, users and institutions. For institutions and utilities, they have the potential to

Figure 1. Smart meter

boost the economy (leading to investments in new real-time metering and pricing technologies), they reduce pollution, they increase the reliability and efficiency of the service (transmitting information gathered from consumers to the data collector) and they help prevent blackouts through more accurate energy forecasts. On the other hand, at the end user side, a *smart* meter shows energy consumption, permits the issuing of more accurate energy bills and enables users to use household appliances correctly. In fact, in a *smart home*, these meters, if coordinated by an ad hoc controller, are the basic source of information in appliance scheduling operations. In addition, their usage helps suppliers to discover any unauthorized consumption of energy (theft), improving the quality of distribution.

Despite the aforementioned strong points, the usage of *smart* meters on a large scale involves important investments, both in terms of distribution and grid network maintenance. Replacing obsolete counters with *smart* meters can be an inconvenient step for service providers initially: existing infrastructures need to be revised and usually meters can only be fully exploited if all appliances and devices in the network communicate. Moreover, the amount of exchanged data between different *smart* meters and the central server is not trivial and even maintenance, storage and management can necessitate an intense workload. Even though managing the exchange and gathering of data is a challenging task, information extracted through *smart* meters is actually used by utilities to model the electricity demand for the optimization of production and distribution.

In the future, *smart* meters will drive this trend and enable the automatic recognition of single appliances in use inside the premises. In this sense, service providers and grid managers will gain an insight into which kind of loads are connected to their grid and, more importantly, customers' habits in nearly real time.

A first classification of the proposed techniques to implement this smart home vision differentiates between top-down and bottom-up approaches (Swan & Ugursal, 2009).

The first class of techniques aims at extracting models based on macro-economic parameters (inflation, unemployment...) useful for regional/national planning, but unsuitable for residential load disaggregation. The second approach instead aims at extracting the single components that characterize the energy consumption. The technique proposed in this approach, in principle, can be scaled from national to single user level.

The most interesting ones are based on Non-Intrusive Appliance Load Monitoring (NILM or NIALM) systems to extend smart meter functionalities beyond AMIs. Several ideas have been proposed in the last 20 years to enable load disaggregation and appliance recognition at single user level, providing the utility with timely information on habits in conjunction with power utilization. The key point is that data are collected through a single point of measurement (Hart, 1992). While the *smart* meter monitors the signal flowing in the home's network to measure consumption, the NILM processes the same signal to identify the unique "signature" of the appliances. Several definitions of "signature" have been proposed in literature that use time- and frequency-domain features but the task is complex and a complete embedded system is a long way from being marketed (Zeifman & Roth, 2011; Butner et al., 2013), confirming that *smart* meters and NILMs are complementary devices.

In short, the *smart* meter design process is strictly related to technological and cost requirements, e.g. maintenance of the communication network, server and *smart* meters, and data protection, security and storage. All these issues influence their improvement and diffusion.

Communication Technologies

RTU (Removal Terminal Unit) and SCADA (Supervisory Control And Data Acquisition) are innovative means with dedicated communication channels to and from WAN (Wide Area Network) and the System Control Centre (Janaka et al., 2012).

The SCADA system mainly connects the major power facilities (like transmission grid, central stations and distribution stations) while WAN connects different hosts, creating a subnet, becoming the backbone of the grid. The *Smart Grid* extends the communication all over the distribution system and grants a bidirectional way of communication for the user through NANs (Neighbourhood Area Networks) and, within this, each user's dwelling/building has a dedicated HAN (Home Area Network).

Essentially, there is an optimal communication technology for each kind of sub-network: the wired and wireless communication technologies available are

- WiMax (Worldwide Interoperability for Microwave Access). Based on the IEEE 802.16 standard, it is specialized in wireless high bandwidth communication point-multipoint.
- MPLS (Multiprotocol Label Switching). Permits, in IP networks, the routing of flows from an input node to an output node through labels between adjacent nodes.
- BPL (Broadband over Power Lines). A means of communication capable of enabling internet access through power lines.
- Wi-Fi. Commonly used, allows devices to connect to each other through a WLAN based on the IEEE 802.11 family of standards.
- Power Line Communication. Permits transmission over the electricity grid, overlapping the electric current flow (50-60 Hz), of a signal with a higher frequency, managed with a proper modulation.

In particular, focusing on two kinds of these technologies could be useful because they are adopted by metering systems to send and/or receive data in the network, according to the scenario.

- Radio Frequency (RF): *smart* meters gather measurements from consumer and transmit them wirelessly to a data collection system. These data are processed and delivered in different ways to the central system, exploiting a mesh (meters communicate with each other) or a point-to-point (meters communicate directly with a central collector) topology, for example.

- Power Line Communication (PLC): the measurements gathered are transmitted through electric lines and later processed and analysed. With this method it is possible to work and communicate over long distances but it has less bandwidth and greater costs.

SCHEDULING OF ELECTRIC LOADS

Local Scheduling

Many scheduling algorithms are available in literature. For instance, in (Leon-Garcia & Mohsenian-Rad, 2010) the authors propose an optimal and automatic residential energy consumption scheduling framework which attempts to achieve a trade-off between minimizing the electricity bill and the waiting time for the operation of each appliance, exploiting linear programming. (Pedrasa et al., 2010) developed a tool that residential consumers can use to optimize their acquisition of electrical energy services. In this case, first the user chooses a schedule, then the algorithm rearranges the appliances based on the available energy resources. The system comprises batteries, PV, and water storage tanks.

(Molderink et al., 2009) aimed at optimizing the consumption on a local scale (a single house) and a global scale (multiple houses). The algorithm divides the planning horizon into intervals and at the beginning of each interval a plan is made for that interval. It is executed iteratively with parameters determined at the beginning of each slot. The goal is to find the best mix of match sources with the lowest cost, using ILP (Integer Linear Programming).

In (Mohsenian-Rad et al., 2010) energy consumption scheduling with several buildings has been addressed by sharing energy sources for autonomous demand side management. So we speak about a distributed algorithm to find optimal energy consumption schedule. However, it is explicitly stated in the paper that the scheduler doesn't change the amount of energy consumption but aims to manage and shift it. Moreover, this work includes an array of batteries for PHEV (plug-in hybrid electric vehicles), avoiding the overload of the network while charging.

The majority of papers usually strictly focus on a single aspect to reduce consumption, while many other parameters and variables could be involved in the process of energy reduction. Every work addresses the issue in a different way: we can find efficient schedulers with a poor level of detail (Kurucz et al., 1996), schedulers adaptable to different scenarios (Mangiatordi et al., 2012) or complex schedulers without taking into account Alternative Energy sources (Nghiem et al., 2011) and so on. Although there are very many, some aspects of the problem deserve further in-depth study. In the following paragraph we present a framework to cover all the possibilities and variables related to a dwelling, to fulfil the needs of householders and to save energy and money.

Scheduling in Urban Areas

The control of energy consumption and efficiency is managed by the s*mart grid* in the whole *smart city* environment. The ultimate goal of this control is to achieve intelligent consumption by users in the *smart city* and increase savings, i.e. better management of resources is a way to save energy and at the same time reduce expense. The application of scheduling algorithms in this *smart city* environment, involving each single node in the network, is a viable solution to help achieve this goal. Obviously along with green energy production plants (PVs, wind turbines…), electrical energy storage systems, and so on.

Schedulers can also provide aggregated data that can be used to extract information about habits and consumption for single dwellings.

A scheduling system for this scenario can be divided in a "top level scheduler" and a "bottom level scheduler". At the top level, the scheduling process concerns the entire *smart* city, a district, a set of users (dwellings or other kind of buildings); at the bottom level, scheduling is typically related to the single-user. The difference is that, from top to bottom level, constraints change: at the top they are related mostly to the energy distribution, at the bottom constraints are focused mainly on a "bounded" energy saving, where constraints can be seen as "objectives". In particular, at bottom level scheduling (i.e. a single user), we can act an arrangement of energy and activities thanks to the presence of the aforementioned NILMs, assuming which appliances are used from the current or voltage trend, and a distributed system capable of measuring costs.

It is important to underline that policies applied in the managing process vary according to the scenario, and are different district by district; for instance, in a district strongly equipped with renewable systems, the power supplier could impose a higher energy tariff with respect to other places to best exploit renewable sources and reduce the possibility of overload.

Introduction to Scheduling Problems

As Monte Zweben and Mark S. Fox (1994) wrote in Intelligent Scheduling, a scheduling process is the selection from among alternative plans and the assignment of resources and time for each activity so that the assignments obey the temporal restrictions of activities and the capacity limitations of a set of shared resources. It is an optimization task where limited resources are allocated over time among both parallel and sequential activities so that measures like tardiness, work-in-process, inventory, and make-span are minimized.

Scheduling problems arise in the context of automation, finding an opportune sequencing of a set of activities that use limited resources, typically machines dedicated to a specific task: the solutions find applications in many areas, from logistics to project management to our case, that is, appliance scheduling in an urban area or dwelling.

In the last 30 years, many authors have worked on this problem and, nowadays, the state of the art allows for the classification and unification of different algorithmic approaches; by the way, in this complex scenario, it's hard to indicate that an approach is better than another.

In a simple way, within a scheduling problem, there are a set of *jobs, which is a specific instance of a Task*. Each *task* has a specified set of features based mostly on *processing time* (the time required to complete a task) and *weight* (the importance of a job with respect to the others).

Moreover, inside a scheduling problem, we can find different architectures of the system: we can have a simple case with jobs requiring the same resources or jobs needing to be executed following a FIFO fashion and so on. Aside from this, a set of constraints can be applied: *precedence constraints* and *blocking* are the most common. The first one indicates the presence of a ranking in the list of jobs, while the second one avoids new jobs while others are running.

A schedule is a complete description of the temporal execution of a set of activities that have to be fulfilled, in accordance with the optimization of the objectives that can be, for example:

- *Completion Time*: The time between the start of the activity and its completed execution. For example, it can be related to a set of jobs or to a single one.
- *Lateness*: The difference between completion time and the delivery date of a job. If it is positive, lateness indicates a delay; otherwise we are in advance respect the due date.
- *Tardiness*: Coincides with the lateness when it is positive, it is zero in the other cases.

The theory on this topic proposes different methodologies and approaches; in this case we will investigate Linear Programming to solve the multivariate optimization problem.

Linear Programming.

From Computer Solutions of Linear Programs, written by John Lawrence Nazareth (1987)

A linear program is an optimization problem defined over a finite-dimensional real vector space, whose solution is required to satisfy a given set of linear inequalities (called constraints) and to minimize or maximize a given linear function (called the objective).

In short, a linear programming (Wosley, 1998) problem may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints, where constraints may be equalities or inequalities.

$$\max\{cx : Ax \leq b, x \geq 0\}$$

where A is an m by n matrix, c an n-dimensional row vector, b an m-dimensional column vector, and x an n-dimensional column vector of unknowns.

Obviously, linear programming involves linear expressions. Occasionally we can have nonlinear terms as x_1^3 or e^{x_1} : this is the major limitation of linear programming but, sometimes, nonlinear expressions can be written in a linear form.

If only some variables are integers, we have a problem called *Mixed Integer Linear Programming*, in a form as

$$\max cx + hy$$

$$Ax + Gy \leq b$$

$$x \geq 0, y \geq 0 \ \ and \ \ integer$$

where A is m by n, G is m by p, h is a p row-vector, and y is a p column-vector of integer variables. Along with this, if all variables are integers we have *Integer Linear Programming*

$$\max cx$$

$$Ax \leq b$$

$$x \geq 0 \ and \ integer$$

Sometimes problems have a large number of feasible solutions. Such problems are named *Combinatorial Optimization Problems*. In a formal way, we can describe the problem as, given a finite set $N = 1,\ldots,n$, .. weights for each $j \in N$ and a set of $\mathcal{F}$ feasible subsets of N, we find the minimum weight feasible subset as

$$\min_{S \subseteq N} \sum_{j \in S} c_j : S \in \mathcal{F}$$

From the above theory, with the necessary limitations and adaptations to the context of a *smart home*, in a *smart city* scenario the proposed scheduling algorithm is based on *Binary Integer Programming*.

Proposed Scheduling Algorithm

The proposed system aims at reducing the energy consumption by solving a scheduling problem regarding home appliances using a photovoltaic module and a storage system. In this way, along with the reduction of energy consumption, comes the economic aspect related to money saving. We will focus our analysis on a single dwelling to demonstrate its effectiveness, which can be "easily" scaled up to the size of the smart grid. Scheduling a set of appliances means ordering them temporally in such a way as to optimize their execution according to some constraints (as mentioned, in our case reduction of energy consumption). A system like this tries to grant the energy autonomy of a dwelling, in particular for the time of day when energy costs are high, exploiting solar radiation with photovoltaic technologies and stocking the energy surplus in a battery, ready for use when needed.

The scheduling problem is solved via *Binary Integer Programming*.

A binary integer programming problem is subject to a restriction where viable results are 0-1 values.

$$\max cx$$

$$Ax \le b$$

$$x \in \{0,1\}^n$$

In this way, we represent a binary choice. This is useful if we consider an event that may or may not occur in our problem, so we have to decide between two different possibilities. Such a dichotomy can be modelled with the above written variable x

$$x = \begin{cases} 1, \textit{if the event occurs} \\ 0, \textit{if the event does not occur} \end{cases}$$

In particular, in our case we based our implementation on a Branch-and-Bound algorithm that makes it possible to compute the optimal solution to the binary integer programming problem by solving a series of LP-relaxation problems. These kinds of algorithms are called implicit enumeration because they behave like an enumeration algorithm, i.e. they try all possible solutions until they find the optimal one. These numerical solvers are provided by many scientific computing libraries.

The first step in defining our algorithm is the reformulation of the binary integer programming problem written above.

$$\min_x f^T x = \begin{cases} Ax \le b \\ A_{eq} x = b_{eq} \\ x \ binary \end{cases}$$

Inequality is related to matrix A and vector b, where we define the constraint connected to the capacity limitations; equality is related to matrix A_{eq} and vector b_{eq}, defining the time constraint of each appliance task. The result is x, a 0-1 vector that imposes the ON/OFF switch for each appliance, aiming to minimize the objective function f, imposing constraints.

To determine the schedule, the above problem can be revised as follows.

With n and m, respectively the number of appliances and functioning time, and X_{ij} Boolean variable related to the ON/OFF state of the i-th appliance in the time slot j, the system is subject to these constraint equations:

1. The energy consumed in one slot by one or more appliances has to be under a certain threshold

$$\sum_{i=1}^{n} E_i X_{ij} \le capacity_{ij}$$

2. Each appliance has a known time to complete its task

$$\sum_{j=1}^{m} X_{ij} \le T_{req,i}$$

3. Objective function is formulated in order to obtain the lower power consumption according to the constraints. In a reduced form, it can be written in this way

$$\min \sum_{i=1}^{n} E_i \left(\sum_{j=1}^{m} X_{ij} Cost_j \right) = \min f$$

Meanwhile, including the free power contribution provided by the photovoltaic unit, it becomes

$$\min \left(\sum_{i=1}^{n} E_i \left(\sum_{j=1}^{m} X_{ij} Cost_j \right) - \sum_{i=1}^{n} \sum_{j=1}^{m} E_{slot_m}^{PV} X_{ij} Cost_j \right) = \min f$$

where E_n is the power consumed by an appliance and $E_{slot_m}^{PV}$ is the generated power. Then, this function is multiplied, element by element, with the priority vector. This vector has the following form

$$P = \left[a \ldots a \right] with \ a = \begin{cases} 1 \\ p \end{cases}$$

where usually -1e05 < p ≪ 0 and a is 1 or p according to what the user imposes, the result is

$$\min \sum_{k=1}^{n \times m} P(k) \left(\begin{array}{c} \sum_{i=1}^{n} E_i \left(\sum_{j=1}^{m} X_{ij} Cost_j \right) \\ - \sum_{i=1}^{n} \sum_{j=1}^{m} E_{slot_m}^{PV} X_{ij} Cost_j \end{array} \right) = \min f$$

Then, this function is used in the minimization problem written above. Here the minimization is completed and the optimization problem is solved by the solver. In the case the solver does not respect the indivisibility constraint, that is

$$T_{req,i} = cs_i$$

where cs_i is the number of contiguous slots needed for appliance i, $i \in n$ and $n(i)$ is an indivisible appliance, it will reschedule. So, appliance i will be forced to switch ON, modifying the P matrix, recalculating f as seen before. With this new objective function, the framework does the minimization problem again.

After the minimization, vector x is multiplied by appliance consumption in order to achieve overall consumption. From this point, the battery is used when permitted by charge thresholds and when we use energy from the grid. The thresholds act on the system as shown in Table 1.

Models

As seen in the description of the algorithm, the scheduling framework assumes the presence of a photovoltaic module and a storage system. Both general purpose models, available in literature, have been shaped accordingly to data from manuals and datasheets of commercial systems.

Photovoltaic Model

Photovoltaic technology exploits the property of semiconductors whereby they release free electrons as a result of interaction with light radiation.

This phenomenon takes place in the photovoltaic cells, made by two silicon semiconductors, gathering solar light, connected together to create a photovoltaic module. Cells can be connected in series or in parallel.

Usually, a PV (Photovoltaic) works in agreement with a set of components in order to achieve a functioning system. These are:

Table 1. SoC management of the household battery

		Allowed Operations	
		Charge	**Discharge**
SoC	SoC = max	X	✓
	SoC > 80%(max)	✓	✓
	Max Price and SoC > 65%(max)	✓	X

- Inverters: used to switch from DC to AC (generally from 12V, 24V, 48V to 220V) to supply a load or introduce to the grid. Normally inverters are equipped with a device called MPPT (maximum power point tracking), able to adapt the characteristics of the production of energy with regard to load needs, extracting the max power from the module instant by instant.
- Interface with the grid: a protection device involved in the event of faults on the grid. This interface inhibits the entry of current of the photovoltaic plant in the grid, in case the grid parameters seem to take harmful values. Practically, it is a protection measure to ensure the security of the grid, the plant and whoever works on the system. Usually, many inverters have the interface included.

Here, the photovoltaic module can be modelled like a voltage source that varies linearly with temperature and sun radiation value (Skoplaki & Palyvos, 2009). The final power derived from the system comes through two different functions: the first one, exploiting the number of days of the simulation, the time division for each day and the number of time slots, achieves the hourly radiation profile, then from this radiation profile, passing it to the second one, with voltage of the photovoltaic panel, time grain and number of time slots, we have the instantaneous power exploitable from the system. The way these functions define the power needs some system parameters like:

- $P_{PV,STC}$ power generated in STC (165 W)
- G_T radiation level (1000 W/m^2)
- γ temperature coefficient (0.043%/°C)
- T_j cell temperature (25 °C)
- $N_{PV,S}$ series-connected cells (6)
- $N_{PV,P}$ parallel-connected cells (12)

Then, the total power generated at the maximum power point, for a single panel, is equal to

$$P_{PV} = \left[P_{PV,STC} \cdot \frac{G_T}{1000} \cdot \left(1 - \gamma \cdot \left(T_j - 25\right)\right)\right] \cdot \left(N_{PV,S} \cdot N_{PV,P}\right)$$

Obtaining the cell temperature T_j from

$$T_j = T_{amb} + \frac{G_T}{800} \cdot NOCT - 20$$

where T_{amb} is the ambient temperature, $NOCT$ is the normal operating cell temperature and, again, G_T is the radiation level. Then the scheduler will decide whether to use it at the moment or to store a part in batteries.

Storage System Model

These are chemical devices capable of storing energy, converting chemical energy into electric energy: they are used to store energy on a large scale within an electrical power grid.

Energy storages, also known as Batteries (Rand & Dell, 2001), are convenient because they are available in different sizes and can be assembled into "packs", they are portable (when not so big) and they are able to supply electrical power instantly. Batteries are mainly divided into primary batteries, in which chemical reactions are irreversible, and secondary batteries (or accumulators), which can be recharged and reused. For the latter batteries, the discharge-charge cycle can be repeated until the capacity to store charge falls below the practical level. Clearly, in our case we choose accumulators. Well-sized batteries make it possible to ensure the continuity of supply even under conditions of low or no radiation or temporary failure of the same. On the market, the kinds of batteries available are:

- Lead-Acid accumulators
- Lithium-Ion accumulators
- Lead-Gel accumulators
- Nickel-Cadmium accumulators

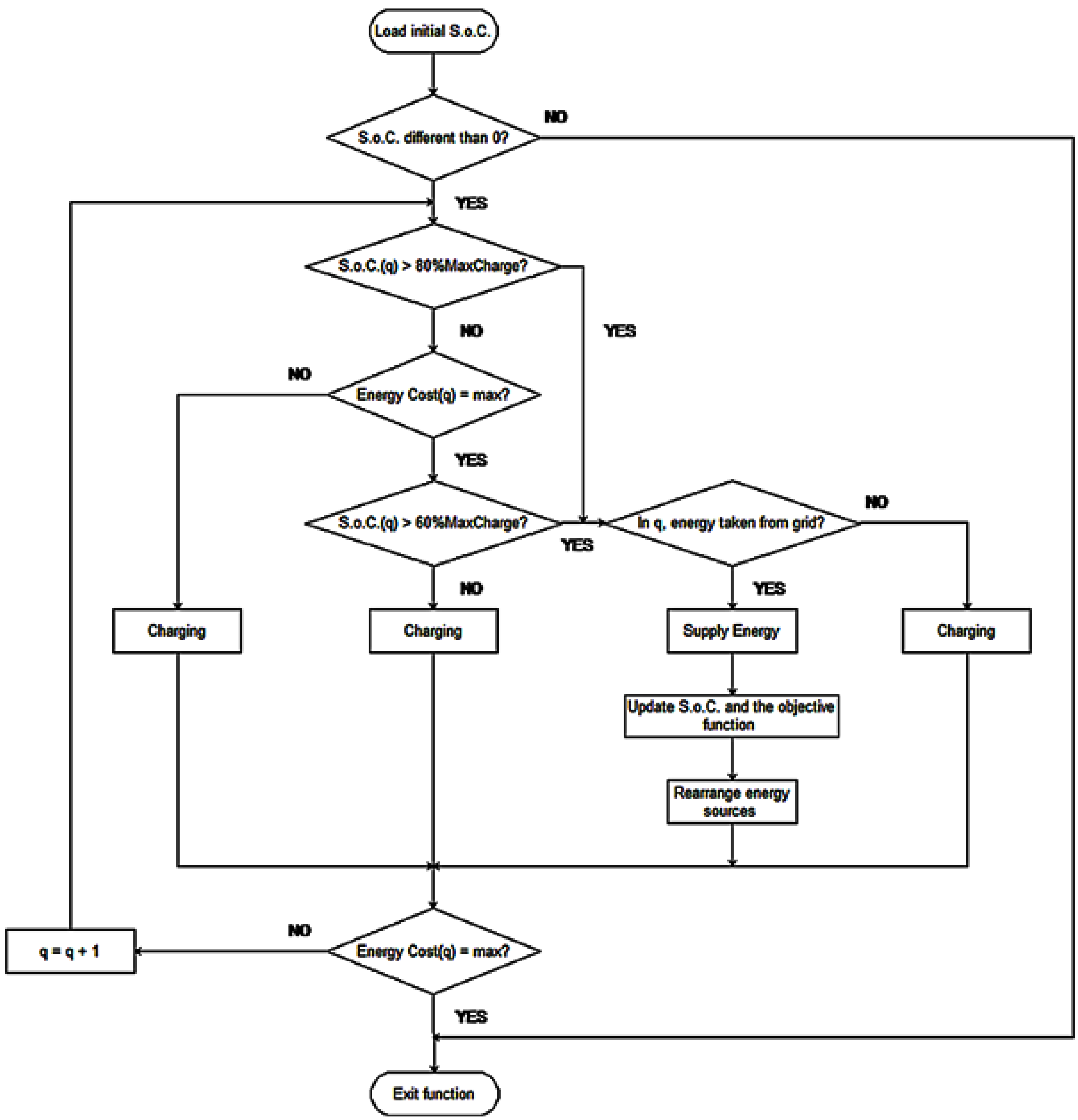
And the most widespread are the first two typologies.

- *Lead-Acid*. Developed in 1859, in almost 150 years they have undergone great evolution and now represent 70% of the worldwide market. Lead-Acid are heavy batteries, relatively cheap and robust. They are able to deliver very high power and easy to produce. Lead-Acid batteries can store energy for a long time and most of the materials used in this kind of storage system (more or less 95%) are recyclable. Moreover, they ensure good energy efficiency (of about 70%), good performances (if used at high discharge levels) and they are able to work at a wide temperature range (-40 °C to 60 °C). Due to these characteristics, they seem to be the ideal choice for storing surplus energy but, at the same time, the low energy density implies a very large battery installation in most cases and the need for significant maintenance. Additionally, if not well managed, lifetime becomes quite short and the risk of the sulfation of the plates increases. Their classification goes accordingly with their applications: we can find SLI (starting, lighting, ignition) batteries for cars; motive power traction batteries for transport vehicles like fork-lift trucks; stationary batteries used for backup in, for instance, telecommunication systems and electric utility systems; special purpose batteries involved in military equipment and batteries for PHEV.
- *Lithium-Ion*. Lithium-ion batteries are constantly evolving, becoming capable of obtaining a voltage three times that of a single unit for nickel-cadmium or nickel-metal hybrid and current capacity respectively more or less doubled. Technically, ions are extracted electrochemically during discharge, migrating through the electrolyte of the host structure. Lithium reacts with water, and the electrolyte is then composed of polymers with non-aqueous lithium salts, acting as a purely ionic conductor. Construction structures are essentially two: cylindrical or flat. Lithium-ion batteries offer a large variety of capacities (usually from 100mAh to 200Ah) and they are characterized by a low self-discharge rate (2%-8% of the whole charge per month). They can sustain a greater number of charge/discharge cycles and are smaller than Lead-Acid ones. Other strong points are their high energy density and high reactivity. As for drawbacks, a major safety hazard exists when they are overcharged or subjected to high temperature. They are also expensive for large scale applications: cost reduction and technological improvements are needed to reduce battery cost to at least 100$/kWh, a sustainable amount to increase their usage in grid applications.

In our case, the storage system supplies energy at the end of the scheduling, using it when needed (i.e. in general to avoid buying energy) and when possible. To clarify, batteries in the scheduler work as per the flow chart in Figure 2.

In short, if the battery is empty, no energy can be used from it, so the management is finished; otherwise, energy can probably be taken from the storage. So, if the SoC in the q-th time slot is greater than the 80% of the maximum charge of the battery, then, if appliances in q are powered with energy from grid (or, from another point of view, if subtracting consumptions from energy

Figure 2. Battery management flowchart



generated with photovoltaic is less than zero), supply energy from the battery to the appliances, else charge the battery. In the case the charge is less than 80%, if q is not in the "high-price" zone, charge the battery, otherwise it checks if the SoC is greater than 60%. If it is true, supply energy from the batteries to the appliances, else store energy. In the end, exit the function if q is equal to the last slot, otherwise go ahead to the next time slot $q+1$.

Functioning of the Scheduler

The framework focuses on providing a simulation as close to a real system as possible, with the necessary specifications. Our scheduler takes a set of appliances, based on priorities, consumption, energy cost and presence of alternative energy, and arranges them in an entire day (or week). It is divided in OFFLINE and ONLINE scheduling phases.

The structure of the framework lets different sources cooperate, at each step making it possible to control a set of constraints related both to energy sources or simply the mere scheduling functioning and management.

It works with hourly time slots: for each time slot, the scheduler decides whether or not to assign an appliance or multiple appliances, according to all the constraints. Before going into detail about the functioning, inputs and outputs must be defined. In particular, the system needs information about:

- Hourly power consumption
- Time requirements for each appliance
- Energy price
- Maximum capacity
- Sizing (PV and storage capacity)
- Priorities
- Indivisibility
- Simulation length (number of days)
- Radiation profile

It provides results on:

- Schedule of appliances
- State of charge of the storage system
- Consumption for each energy source
- Information to evaluate performances (expenses and savings).

With these inputs, the framework elaborates a schedule following the flow chart in Figure 3.

Essentially, at the very beginning there is the initialization of all the variables involved in the scheduling process (e.g. time requirements, priorities etc.). Then, the scheduling cycle occurs. The radiation profile is managed and converted into usable power by the household, after which all the variables used by our scheduling function (including the objective function) are created and the real OFFLINE scheduling takes place. A check on all the indivisibility constraints is made: whenever an indivisible appliance is not scheduled in contiguous slots, priorities are modified in order to force indivisibility and a rescheduling is carried out.

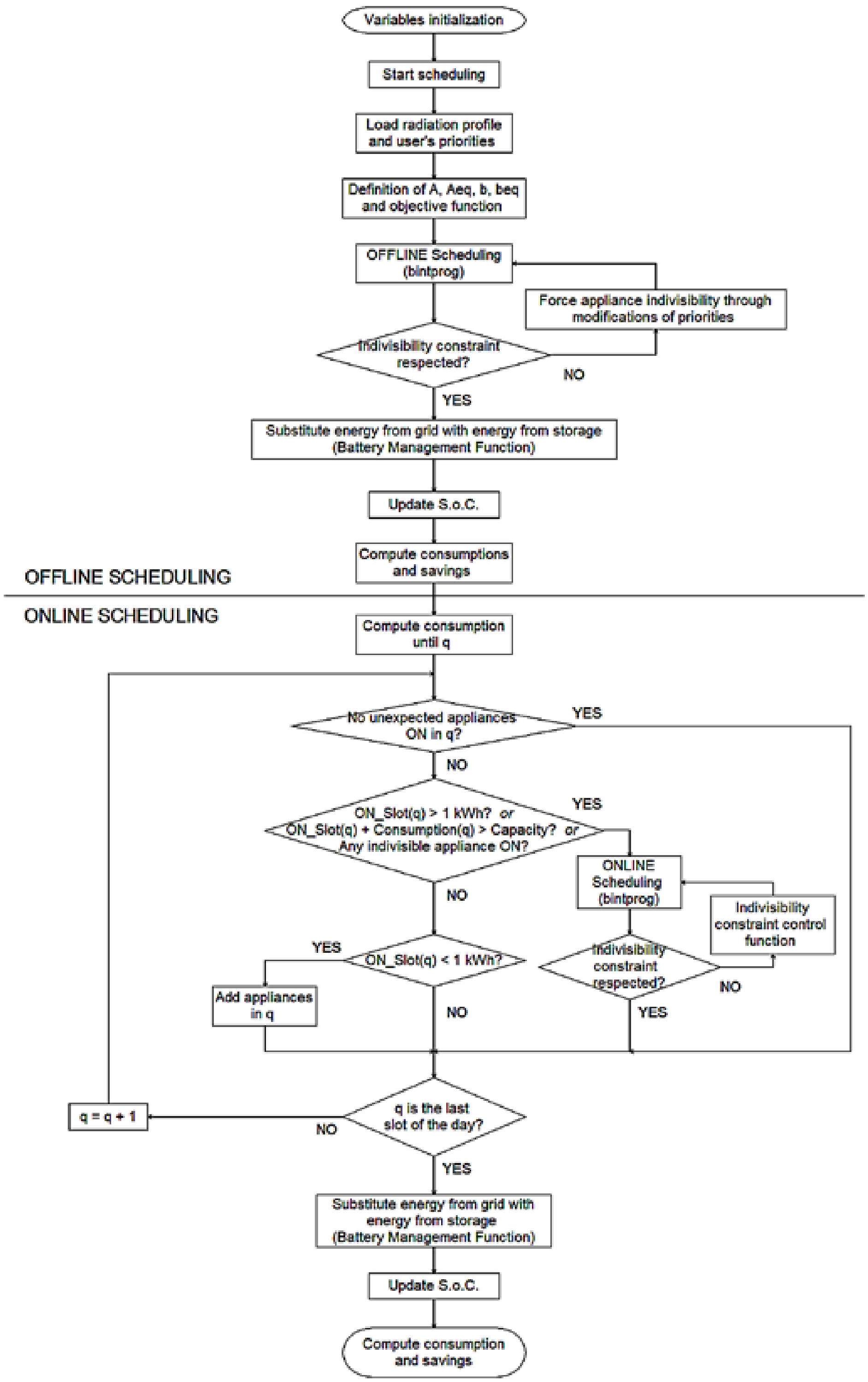
Here we obtain a schedule of the appliances related to energy cost and sun radiation: the next step is to introduce and include the energy contribution by the storage part. As seen previously, the storage part is managed with an external function, which establishes whether or not to use its energy according to the SoC and energy price. Therefore, energy from the grid is substituted with energy from the storage: in this way we generally reduce expenses given that the energy that fills the battery is taken for "free" from the sun. After updating the SoC, consumption and savings are computed.

At this point, the OFFLINE scheduling ends. From now on we will speak only about ONLINE scheduling.

It starts computing energy consumption from the beginning of the first day to the first slot (we speak about the q-th slot, and it is equal to a single hour) where, if one of the constraints is not respected, the framework reacts. The constraints are:

- Consumption of the desired appliance (or appliances), to switch on when not expected, is over a threshold (usually we impose 0.8-1 kW).
- Consumption of appliances in the q-th slot plus the consumption of the unexpected appliances is over the capacity (here is 3.3 kWh).

Figure 3. Scheduler flowchart



- Indivisible appliance switched on when not expected.

Again, if not respected, the framework carries out a rescheduling from q to the end of the day, ensuring the indivisibility constraint is satisfied.

Then, if the constraints are respected, it checks if the appliance is under a certain threshold and it simply adds the load to the schedule in q, otherwise it means that in q no unexpected appliances are switched on. Afterwards, it manages energy from the storage and updates the SoC. In the end, it computes consumption and savings.

SIMULATIONS AND RESULTS

In this section, we are going to see how our algorithm schedules the appliances in a defined period, observing how the scheduler behaves according to each different situation and configuration.

In the framework, we use a radiation profile of an entire week, related to intense regular radiation, for instance, sunny for the 80% of the days (see Figure 4 and 5).

We impose a set of appliances to get an approximate average yearly consumption of between 2700 and 3300 kWh/year, according to their consumption pattern. With a fixed maximum energy from the grid imposed at 3.3 kW, the dwelling, in the “complex” case, is equipped with a photovoltaic module (2.35 kWp) and a storage system that can provide 4 kW at its maximum state-of-charge (SoC). Along with this, a fixed energy price model is proposed: it is simply a bi-hourly tariff, taken from a real tariff proposed by an energy supplier in Italy. From 8 a.m. to 6 p.m. the high price (0.24 €/kWh) is applied, while from 7 p.m. to 7 a.m. the cost of the energy is lower (0.21 €/kWh).

Figure 4. Weekly radiation profile

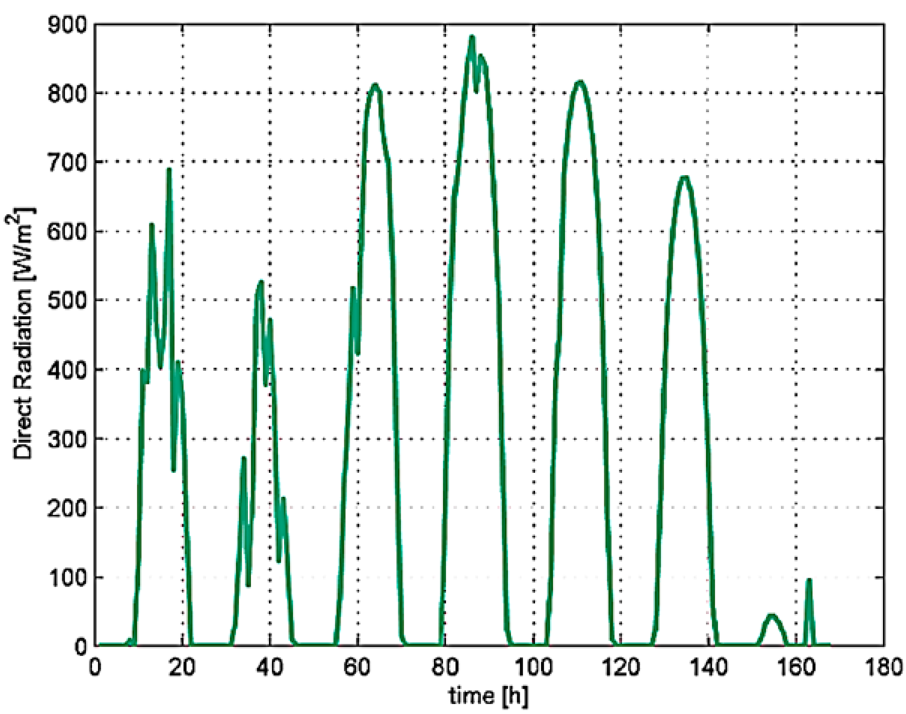
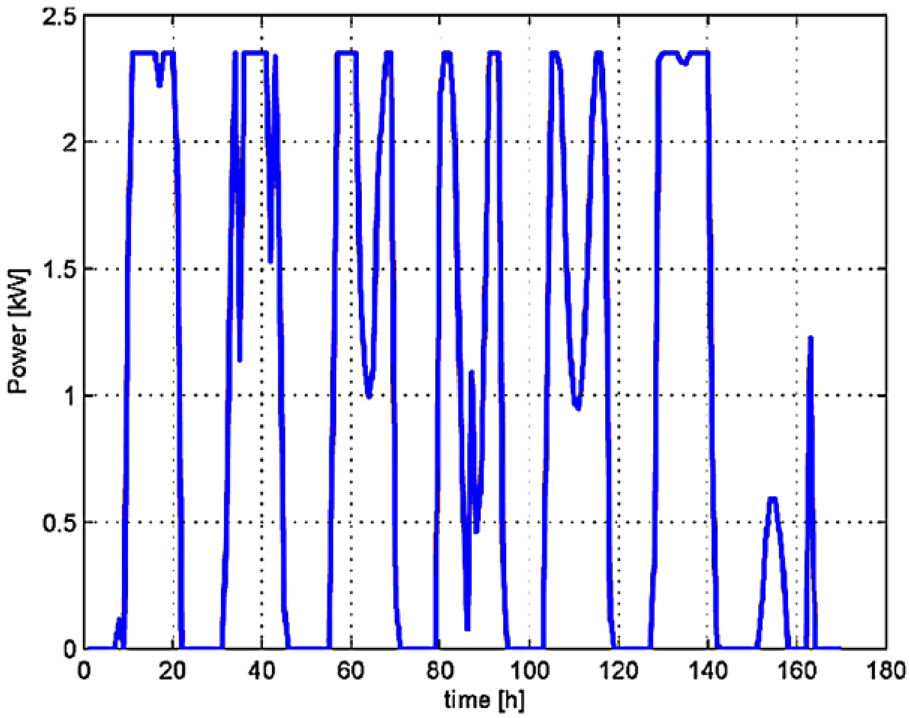


Figure 5. Power produced by the photovoltaic module according to weekly radiation profile



Performances and metrics are measured as:

- Power consumption and usage.
- Expenses, money savings and return on investment.

Power consumption indicates how much the system is dependent on the grid: the less or the better we use grid energy, the more we are "autonomous" in supplying our loads, consuming less, saving more. This aspect becomes crucial when we have the support of alternative energy, where we're able to manage loads in order to use as little grid energy as possible. So, in this case, we positively evaluate when alternative energy is preferred to grid energy or, if not possible, is well managed.

Generally speaking, if we have an alternative energy source, common knowledge would say that there will be a guaranteed saving. Actually this is not true! If the sizes are not correct, the money invested may not be compensated. For instance, if we use the photovoltaic energy system in a dwelling with a poor solar light radiation or a plant of the wrong size, we may not be able to earn money for the payback. Here, clearly, we have a positive behavior whenever we get savings and we are able to pay our investment (in photovoltaic, storage, wind power etc.) in a reasonable period.

To compute consumptions and savings and breakeven costs, we run the simulation for several years, repeating single week patterns: the results in this case will be closely investigated as regards the economic metric.

In Table 2 the consumption, time requirements, hourly priorities, indivisibility constraints and additional ONLINE time requirements used in our examples are shown.

As mentioned, the framework can work in different configurations: from a dwelling equipped only with the scheduler, to a dwelling equipped with renewables (photovoltaic and/or energy storage) and an energy manager given by the scheduler.

In the next part we are going to describe in detail the simulation of a scenario where the scheduler acts on a dwelling with a photovoltaic module and a storage system. After this analysis, we will briefly discuss the behavior of the scheduler in different scenarios (dwelling without renewables, dwelling only with photovoltaic, dwelling only with storage system) to provide an overview of its functioning.

Basic Functioning with Photovoltaic Module and Energy Storage

This is the most complex case. The dwelling is equipped with a photovoltaic module and energy storage.

First of all, SoC (Figure 6 (c)) has an irregular trend: at the beginning, the first charge phase comes when we have surplus energy from the sun, where the sun is more or less an unpredictable source. Without a storage system, the surplus energy is wasted, while, when we adopt a battery bank, with q as a generic time slot, we have surplus energy if

$$PVEnergy(q) - \sum_{i=1}^{n} E_i(q) X_{iq}$$

is greater than 0, and, in line with the battery management, we store energy in order to use it when needed in the future.

A first OFFLINE process arranges the appliances (shown in Figure 6 (a)) depending on the scheduling algorithm, weighting energy price and sun radiation forecast.

Then, according to the OFFLINE → ONLINE pattern and the rescheduling constraints, the steps to the final scheduling are plotted in Figure 6 (b). It takes two whole rescheduling steps because the user turns on unexpected appliances with power consumption over the threshold (in our case 0.8 kWh), so, the framework updates the whole scheduling twice, the first time at 11 a.m. and then at 18 p.m..

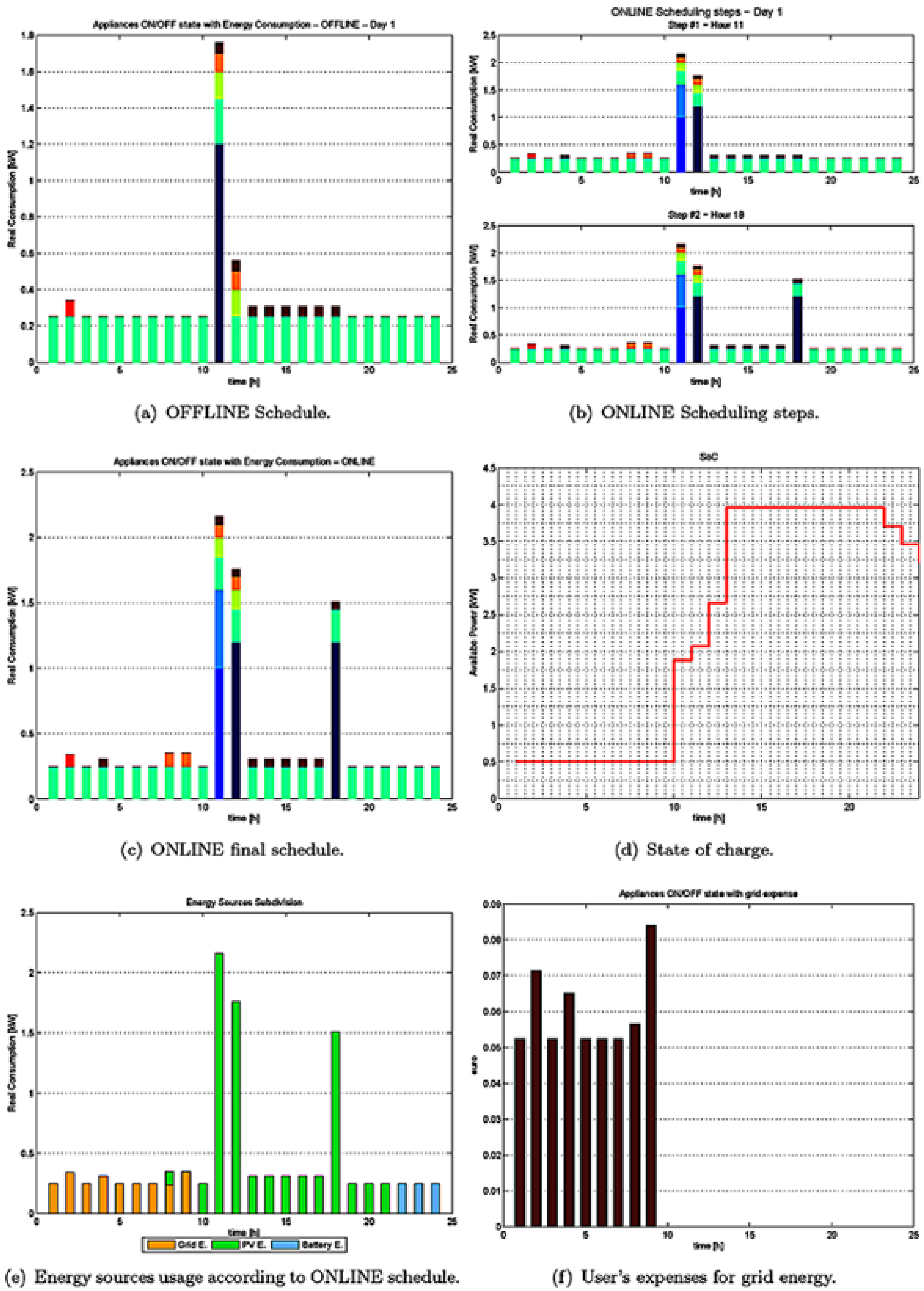
Referring again to Table 2, the final schedule executed during the day is the one shown in Figure 6 (c).

The framework provides additional indications about the state of charge of the battery bank (Figure 6 (d)), where the algorithm tries to charge the storage system during daytime hours

Table 2. Appliance consumption and scheduling patterns

Appliances	Type	Consumpt. [kWh]	T_{req} [h]	Prioritized	Indivisible	Online On/ OFF T_{req} [h]	Color
App1	Dishwasher	1.2	1	X	X	1	Navy
App2	Iron	1	0	X	X	0	Blue
App3	Washing machine	0.6	0	X	X	0	Deep Sky Blue
App4	Fridge	0.25	24	X	X	0	Aquamarine
App5	TV	0.15	2	X		0	Green Yellow
App6	Computer	0.1	2	X		2	Dark Orange
App7	light	0.09	1	X	X	0	Red
App8	light	0.06	8	X	X	1	Fire Brick

Figure 6. Single day scheduling graphical results in the case of a photovoltaic module supported by a storage system



(a) OFFLINE Schedule.

(b) ONLINE Scheduling steps.

(c) ONLINE final schedule.

(d) State of charge.

(e) Energy sources usage according to ONLINE schedule.

(f) User's expenses for grid energy.

exploiting solar radiation and to use this energy at night-time. This behavior can be observed in Figure 6 (e), depicting energy subdivision according to energy source. Finally, in Figure 6 (f) we can see the expenses trend, not very significant in a single day observation.

The overview given by the weekly simulation is really useful (Figure 7). We can clearly see that storage behaves in line with the constraints imposed to improve its lifetime (SoC can't be lower than the 60% of its maximum value). While the schedule respects the rules and constraints widely described above (Figure 7 (a) and (b)), the trend followed by SoC almost becomes a pattern (Figure 7 (c)). The reason is simple: scheduler supply loads mostly with photovoltaic energy during the daytime but, when the sun goes down, the storage system (charged with energy in surplus from the sun) supplies appliances. There, when we reach the lower limit, the battery can only be charged. It will wait for the next surplus energy to be charged and, in the meantime, the scheduler uses grid energy. This cycle repeats every day.

Moreover, as we can see, expenses are drastically reduced and, in an energy subdivision plot (Figure 7 (d)), there are few yellow color bars for grid energy compared to photovoltaic (green) and storage (blue sky) energy. Using a photovoltaic module combined with a storage system results in the very poor usage of grid energy: it is surely a saving in the present but we must relate savings and costs to the initial investment (Figure 7 (e)).

Briefly, the energy subdivision through the adoption of our algorithm is clear: the framework uses alternative energy sources every time this is possible. In the daytime, there is enough solar radiation to avoid grid energy usage, while, at the end of the day the storage system covers part of the consumption as far as possible.

Basic Functioning

This is the "simplest" scenario: the scheduler optimizes the solution only on the knowledge of the energy price model, in our case a bi-hourly tariff. Except for possible priorities, the optimization arranges all the appliances at night-time. A behavior like this is obvious: in that zone, the energy price is lower and, without any other energy source, we limit the expenses. The ONLINE scheduling depends on the three conditions cited in the "scheduling functioning" paragraph. Source subdivision is composed only by energy from grid and expenses strictly trace out the power consumption trend.

To sum up, except for priorities and indivisibilities, appliances are mainly allocated in the low price time-slots.

Basic Functioning with Photovoltaic Module

From the previous case, our dwelling is equipped with a photovoltaic module: we have another energy source as support. Here the schedule is completely different from the previous case: the distribution of appliances over the day is concentrated in central time slots (in general from 10.00 to 15.00). This is due to solar radiation in the middle of the day: the structure of the scheduler aims at reducing costs so arranging appliances where we have "free" energy is a logical consequence.

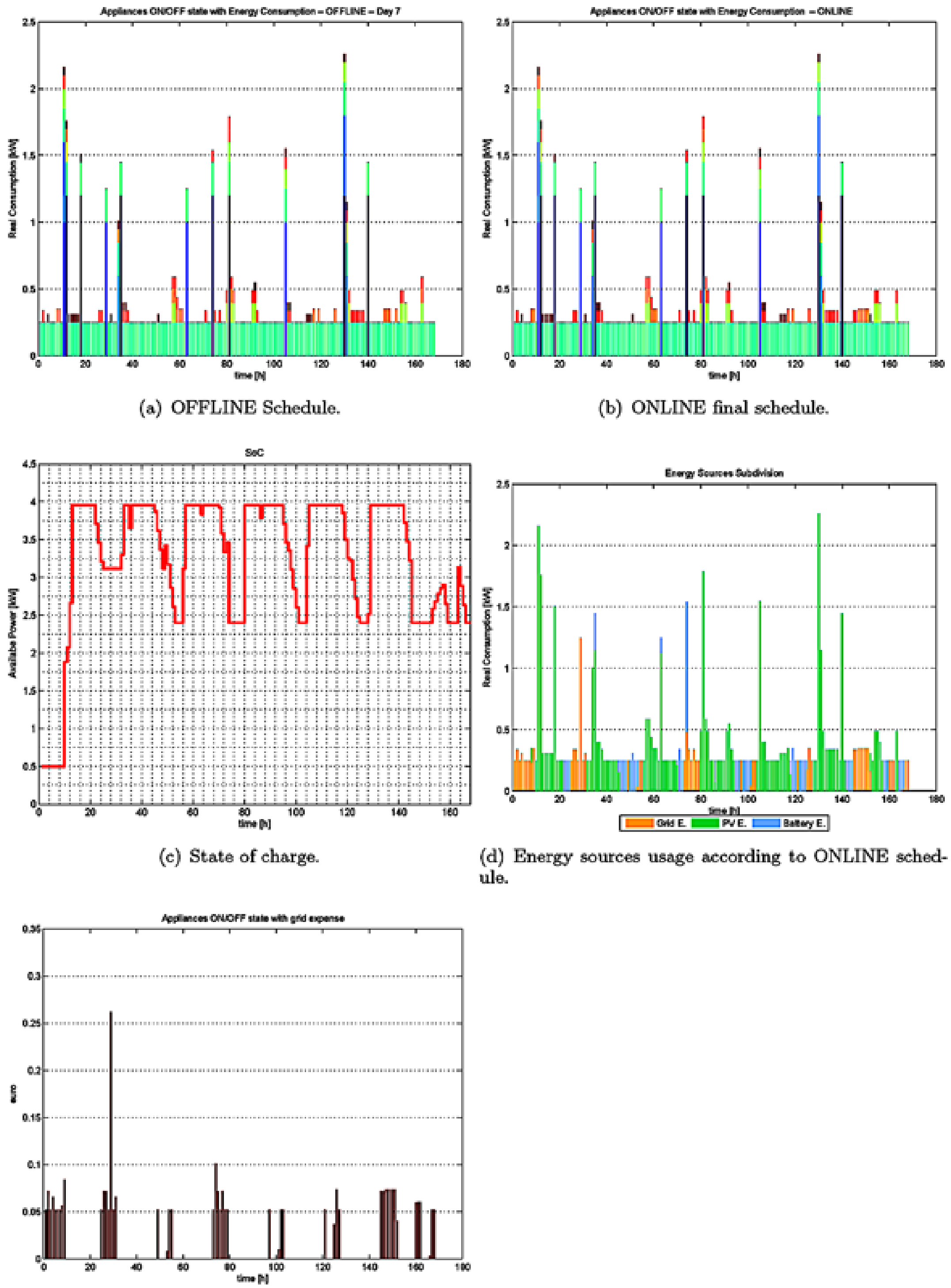
The point is that part of the photovoltaic energy is wasted when our appliances consume less than the available energy.

From simulations in this scenario, we can say that the system uses energy from the grid for approximately half of its functioning time, the other half is photovoltaic energy. The same goes for expenses: it seems that we break down the costs, spending half as much money.

Basic Functioning Plus Energy Storage

According to the algorithm, energy from the storage system is used after optimization to avoid using

Figure 7. Weekly scheduling graphical results in the case of a photovoltaic module supported by a storage system



(a) OFFLINE Schedule.

(b) ONLINE final schedule.

(c) State of charge.

(d) Energy sources usage according to ONLINE schedule.

(e) User's expenses for grid energy.

energy from the grid, so appliances are scheduled in the same way as basic functioning.

The fundamental difference is that, with the storage part, we reduce the expenses. For example, in the middle of the day, when the energy price is high, we exploit the stored energy while, in the low price hours, we use energy to charge the battery. Compared to the case with a photovoltaic module, here expenses are greater: to achieve better results, batteries can be sized in different manners. Probably we will have greater daily savings, but the initial investment may not be repaid. SoC somehow follows the constraints imposed implicitly by the bi-hourly tariff:

- In low price hours: the storage system charges with energy from grid.
- In high price hours: the storage system provides energy to the appliances (i.e. a discharge phase), substituting energy from the grid, according to its management.

To sum up, in this case, appliances are generally arranged like the basic functioning case (here we cannot base on both energy price and solar radiation), exploiting storage energy during the daytime. When the energy from the storage system is not enough to power all the scheduled appliances, energy intake from the grid is used.

Savings and Costs

With an average annual consumption of between 2700 and 3300 kWh/year (which is a statistical range of energy consumption assessed in some countries, such as Italy), the Residential hybrid energy scheduler can be sized with 2.35 kWp PV panels and the cost of the system can be evaluated to be:

- PV = 2.35 kWp × 5 €/W = 11750 € = 8660 €
- Battery = 2.35 kWp × 2 €/W = 4700 € = 3464 €
- Installation = 2.35 kWp × 2 €/W = 4700 € = 3464 €

Assuming this reasonable system, we calculated the Return on Investment and the money saving which can be appreciated in the energy bill, using the annual solar energy profiles and power consumption of a typical household. Assuming an annual energy bill for electricity of about 762 €, the framework shows how different configurations of the system can provide different amounts of saving and intervals for the Return on Investment.

As we can see in Figure 8, PV leads to greater savings and fewer years to recoup while, with a single storage system without PV, we need a lot of years to recoup, and this is clearly inconvenient, as summarized in Table 3. The number of years to recoup our investment can be reduced by selling the surplus energy (0.1 €/kWh for example), achieving results like in Table 4. In short, by using the scheduler on its own (i.e. arranging appliances with the energy cost model) we don't achieve huge savings: installing a scheduler (for example inside a router) could be affordable so, maybe not in a single year but over a decade, the saving can be potentially significant. The best investment might be a photovoltaic module: the saving is high but not the highest compared to each functioning mode. Despite this, the investment is paid back in 15 years, the shortest time in our simulations.

A storage system is more convenient than the single scheduler, but such an investment is strongly discouraged, while a storage system combined with PV leads to a considerable saving with a reasonable recoup time.

When we sold energy, the results are different: the recoup time is smaller.

As we can see in Table 4, selling surplus energy is more convenient than wasting it. We reduce recoup time by 8-9 years each. With this, a user could think of a bigger and more powerful plant: though a precise and good sizing this could lead to a more autonomous dwelling and a greater

Figure 8. Trend of expenses according to functioning modes

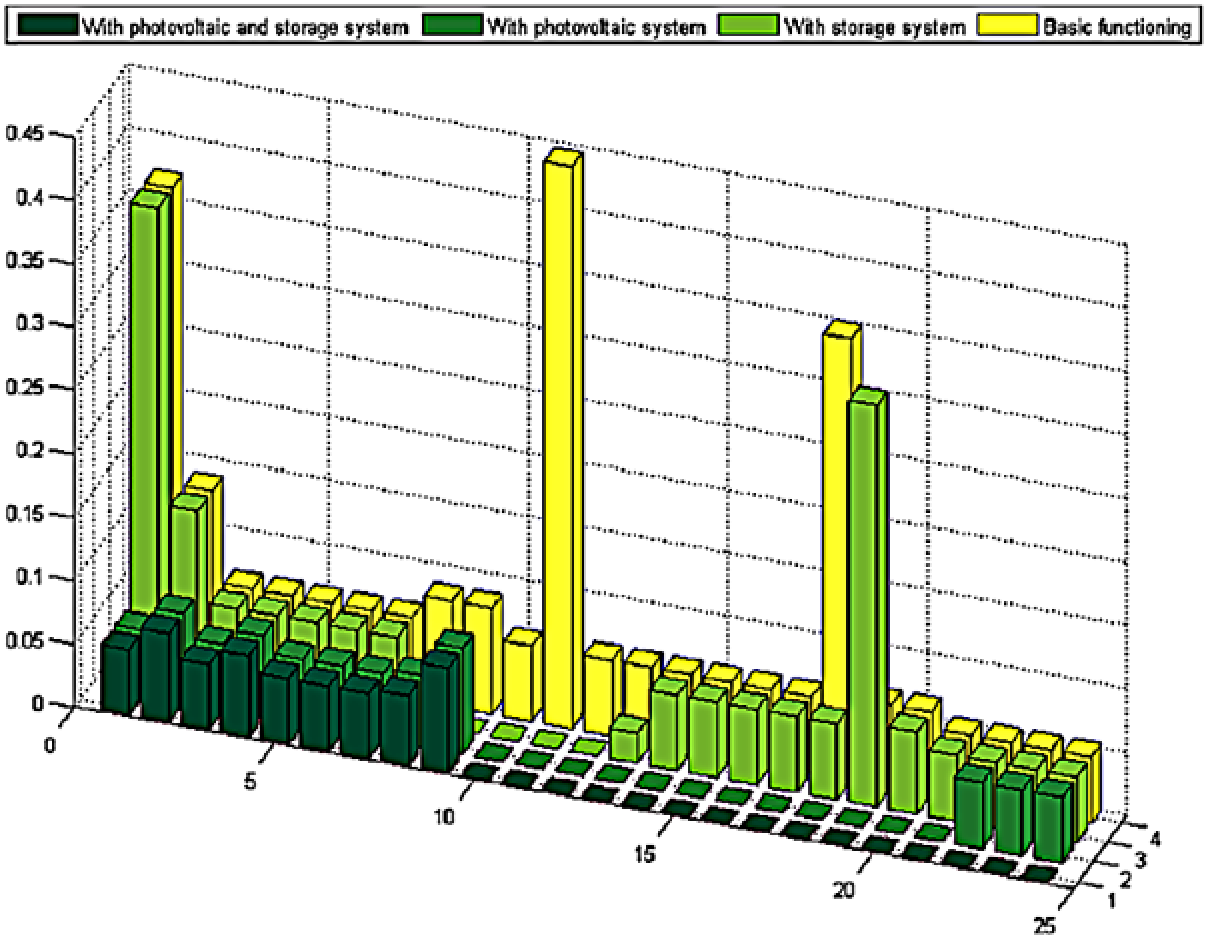


Table 3. Expenses and savings according to energy sources in the dwelling

Functioning Mode	Basic Scheduling	With PV	With Storage	With PV and Storage
Expenses	741 €	247 €	718 €	151 €
Savings	21 €	514 €	43 €	611 €
Cost Recoup (years)	×	15	228	19

Table 4. Cost recoup in the case of sold energy

Functioning Mode	With PV	With PV and Storage
Cost Recoup (years)	7	10

quantity of sold energy, always according to the limitations and constraints imposed by the law.

Generally, the results are much better when adding a PV. Through an initial investment, we recoup our money in a reasonable time and money savings are relevant. Energy is well managed: simply, the scheduler tries to exploit all the solar radiation instantly. When the PV cooperates with a storage system the results in terms of money savings and energy savings are superior if compared with all the other cases.

FUTURE RESEARCH DIRECTIONS

Improvements are expected when expanding the concept of load scheduling to a set of dwellings cooperating with each other, or maybe changing completely scenario, adapting the framework for an industry and a production process.

It could be interesting to insert other alternative energy sources, like wind power: in this way it will be possible to see how a different source interacts with the schedule and with the other sources, and furthermore make the scheduler more complete and customizable. Another point could be the inclusion of a cogeneration system for thermal energy.

For sure it could be useful to introduce means for the better sizing of the alternative energy plants: in this way the simulations are more similar to reality, so we will have more reliable results. Obviously, this could increase the difficulties in understanding and using the framework.

Another idea is to refine the scheduler passing, for instance, to temporal slots of 30 minutes or less: doing this we get closer to the process of making the framework more similar to reality, as mentioned. With smaller slots we refine the time subdivision and this will certainly add complexity and computation time to the scheduler, but with the correct trade-off, this shouldn't be a problem.

Clearly, this work can be the starting point for a set of future improvements and developments.

CONCLUSION

In this work we dealt with Smart Grids, Alternative Energies and the scheduling of appliances in the residential environment to manage energy usage and lower grid energy consumption. With a growing need to be more environmentally friendly, the integration of renewables is crucial in a smart system aimed at optimizing and innovating environmental management.

This management, involving citizens in public policy, should be able to improve the economy and ease mobility and facilities; moreover, given that citizens are the most important part of a city, developing a smart system as seen in this chapter leads to a better quality of life.

In particular, we propose a way to reduce the consumption of energy from fossil fuels in order to increase sustainability, reduce pollution and save money: we analyze the behavior of a residential hybrid system equipped with a photovoltaic and storage system, assuming that we have a set of means to control, manage and arrange appliances and electricity flow.

We show a scheduling algorithm that is able to act on the system, arranging appliances according to users' habits and needs and the state of the energy sources involved. With the possibility of assigning priorities, along with the presence of alternative energy sources and the ability to cope with possible errors in the forecast of expected solar radiation, the scheduler is a powerful tool supported by a double optimization related to the two scheduling phases. Moreover, the framework is adaptable to different scenarios and permits the changing of parameters such as the number of appliances, power consumption, size and other parameters.

REFERENCES

Aldrich, F. K. (2003). *Inside the Smart Home*. London, UK: Springer.

Butner, R. S., Reid, D. J., Hoffman, M., Sullivan, G., & Blanchard, J.(2013). Non-Intrusive Load Monitoring Assessment: Literature Review and Laboratory Protocol. Retrieved from http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22635.pdf

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2012). Smart Grid and Smart Homes: Key Players and Pilot Projects. *IEE Industrial Electronics Magazine*, *6*(4), 18–34. doi:10.1109/MIE.2012.2207489

Hart, G. W. (1992). Nonintrusive appliance load monitoring. *Proceedings of the IEEE*, *80*(12), 1870–1891. doi:10.1109/5.192069

Janaka, E., Jenkins, N., Liyanage, K., Wu, J., & Yokoyama, A. (2012). *Smart Grid: Technology and Applications*. New Jersey: Wiley.

Kurucz, C. N., Brandt, D., & Sim, S. (1996). A linear programming model for reducing system peak through customer load control programs. *IEEE Transactions on Power Systems*, *11*(4), 1817–1824. doi:10.1109/59.544648

Leon-Garcia, A., & Mohsenian-Rad, A.-H. (2010). Optimal residential load control with price prediction in real-time electricity pricing environments. *IEEE Transactions on Smart Grid*, *1*(2), 120–133. doi:10.1109/TSG.2010.2055903

Mangiatordi, F., Pallotti, E., Del Vecchio, P. & Leccese, F. (2012). Power consumption scheduling for residential buildings. *Environment and Electrical Engineering*, 926-930.

Mohsenian-Rad, A. H., Wong, V. W. S., Jatskevich, J. & Schober, R. (2010). Optimal and autonomous incentive-based energy consumption scheduling algorithm for smart grid. *Innovative Smart Grid Technologies*, 1-6.

Molderink, A., Bakker, V., Bosman, M. G. C., Hurink, J. L., & Smit, G. J. M. (2009). *Domestic energy management methodology for optimizing efficiency in Smart Grids. In proceedings of* (pp. 1–7). IEEE Bucharest PowerTech. doi:10.1109/PTC.2009.5281849

Momoh, J. (2012). *Smart Grid: Fundamentals of Design Analysis*. New Jersey: Wiley-IEEE Press. doi:10.1002/9781118156117

Nazareth, N. J. (1987). *Computer solutions of linear program*. New York, NY: Oxford University Press.

Nghiem, T. X., Behl, M., Mangharam, R., & Pappas, G. J. (2011). Green scheduling of control systems for peak demand reduction. In *Proceedings of Decision and Control and European Control Conference* (pp. 5131-5136). doi:10.1109/CDC.2011.6161164

Pedrasa, M. A. A., Spooner, T. D., & MacGill, I. F. (2010). Coordinated Scheduling of Residential Distributed Energy Resources to Optimize Smart Home Energy Services. *IEEE Transactions on Smart Grid*, *1*(2), 134–143. doi:10.1109/TSG.2010.2053053

Rand, D. A. J., & Dell, R. M. (2001). *Understanding Batteries*. Great Britain: Royal Society of Chemistry.

Ricquebourg, V., Menga, D., Durand, D., Marhic, B., Delahoche, L., & Christopher, L. (2006). The smart home concept: our immediate future. In *Proceedings of IEEE International Conference on E-Learning in Industrial Electronics* (pp. 18-20). doi:10.1109/ICELIE.2006.347206

Seisdedos, G. (2012). ¿Qué es una Smart City? *BIT Numerical Mathematics*, *188*, 35–37.

Skoplaki, E., & Palyvos, J. A. (2009). On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar Energy*, *83*(5), 614–624. doi:10.1016/j.solener.2008.10.008

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable & Sustainable Energy Reviews*, *13*(8), 1819–1835. doi:10.1016/j.rser.2008.09.033

Wispes srl. (2010). *Wireless energy autonomous meters*. Retrieved from http://wispes.com/

Wosley, L. A. (1998). *Integer Programming*. New Jersey: John Wiley and Sons Inc.

Zeifman, M., & Roth, K. (2011). Nonintrusive appliance load monitoring: Review and outlook. *IEEE Transactions on Consumer Electronics*, *57*(1), 76–84. doi:10.1109/TCE.2011.5735484

Zweben, M., & Fox, M. S. (1994). *Intelligent Scheduling*. San Francisco, CA: Morgan Kaufmann Publishers.

KEY TERMS AND DEFINITIONS

Building Management Systems (BMS): A control system (algorithm) integrated with modern buildings heavily equipped with sensors and automatic systems (heating, ventilation, air conditioning, surveillance, alarms, electronic doors...) able to collect, process and extract knowledge from the building itself and the surrounding environment and capable to take the optimal actuations to automatically fulfill the comfort and quality of life requirements for the inhabitants, maximize the building lifetime, lowering its environmental impact, operational costs and maintenance.

Hybrid Energy Storage Systems (HEES): Electronic systems capable of storing electrical energy for non-immediate use. It may consist in a set of batteries of various technologies (lead-acid, lithium-ion and so on) arranged in a matrix to achieve the required storage capacity where the heterogeneity of technologies allows to mitigate the drawbacks and maximize the effectiveness.

Hybrid Residential Electrical Systems (HRES): Buildings where photovoltaic or other renewable sources are installed along with the traditional connection to the electricity grid, these are active entities in the network, also referred as prosumers.

Photovoltaic Systems: Electronic modules able to convert solar irradiance into electrical energy, usually arranged in arrays or matrices to fulfill the electricity demand of single houses (12 to 14 modules), buildings (matrices with up to hundreds of modules) or cities (set of matrices usually placed in the country).

Renewable Energy Sources: Sun, wind, waterfalls, tides and other natural energy reservoirs, naturally replenished, that can be exploited to generate electrical energy and have a low environmental impact with respect to fossil fuels thus reducing wastes, carbon emissions and global warming.

Residential Load Scheduling: A control system (algorithm) interfaced with domestic appliances (washing machines, TV-sets and so on), the house and the electricity distribution grid (service provider) able to automatically manage the electronic devices according to several policies, integrating user habits, requirements from the service provider, time of the day and so on. For example in case of network maintenance the system can postpone the dishwasher from morning to afternoon, automatically, while the user is at work, at the same time fulfilling the requirement to get the service complete by 6pm. In the same way it is possible for the user to turn on all his appliances (oven, dishwasher, washing-machine) and the system will take care of the overload limit by scheduling them based on previously set preferences.

Smart Grid: The electric energy network of the future, where bidirectional flow of energy will be possible both at transmission and distribution levels, where end users will become prosumers (double role of producers and consumers of electrical energy) and information about network health, power flows, statistics and consumption will be exchanged and be available in real-time.

Chapter 10
An Innovative Approach to Vehicle Electrification for Smart Cities

Promiti Dutta
Columbia University, USA

Roger Anderson
Columbia University, USA

Albert Boulanger
Columbia University, USA

Leon Wu
Columbia University, USA

ABSTRACT

Vehicles, both personal and commercial, have become ubiquitous forms of transportation in the developed world. The auto industry is amidst a technological transformation in identifying alternative sources of energy to power vehicles due to two driving forces: environmental pollution prevention and depletion of fuel resources. This driver for developing "smarter" solutions to create a "smarter planet" is crucial to advancing the science behind electric vehicles (EVs). EVs have been in existence since the mid-19th century, and electric locomotion has been the commonplace in many other vehicle types such as trains. The focus of this chapter is to discuss the feasibility of EVs in smart cities. In particular, the chapter explores the types of EVs, advantages and challenges faced by EVs to penetrate the market, and to outline state-of-the-art research and technologies that are driving the creation of newer and better EVs for adoption in the smart cities of tomorrow.

INTRODUCTION

While the internal combustion engine has been the predominant energy choice for vehicles for more than a hundred years (Tauber, 1995), there has been a push in recent years to find alternative fuel sources to the traditional gasoline powered vehicle due to environmental, health and political concerns. Between environmental pollution and fossil fuel availability concerns, the electric vehicle market has been evolving relatively quickly (Harris, 2009). In 2011, President Obama announced in his State of the Union address that his administration would push to have 1-million electric vehicles one the road by 2015. Currently, the main hurdle with adoption of EVs is due to their limited driving range and ease of recharging.

DOI: 10.4018/978-1-4666-8282-5.ch010

Environmental concerns include general pollution including air emissions as well as availability of the fossil fuels in the future. Even though modern day vehicles have made several advancements in reducing the toxic emissions and improving fuel efficiency, there has been a steady increase in emissions in the past two decades. While, this may be due to the increasing number of vehicles on roadways, there is still a need to find a method to reducing the amount of emissions again. Reducing carbon dioxide emissions to mitigate climate change is a leading issue (Boulanger, et. al., 2011) as well as the concern about the availability of natural resources in the future to sustain the needs for running a gasoline-based vehicle.

Health effects from exposure to gasoline (i.e. filling gasoline tank, gasoline leak from engine, and general gasoline spills and accidents) are not mild. Exposure to high levels of gasoline chemicals can lead to cancer. Long-term effects of occasional exposure to gasoline are not widely known, however, inhalation of fumes can lead to dizziness, headaches, confusion and breathing issues.

Dependence on vast amounts of oil also has its political issues and can be of particular concern with the general availability of this resource. Currently, the Middle East is a large supplier of oil for the world given its large deposits in that region. Other countries such as Iran and Venezuela also have large deposits of oil available in their region. Therefore, these countries have an inherent stronghold on other countries because of their precious commodity. Being able to find other methods so that a country is not dependent on other particular countries for resources, helps maintain independence.

TYPES OF ELECTRIC VEHICLES

Electric vehicles are referred to as green vehicles by some as a solution to the internal combustion engine vehicle for carbon emissions. Electric vehicles originated in the mid-19th century when electricity was one of the preferred methods for motor vehicle propulsion. An electric vehicle uses one or more electric motors for propulsion. There are many kinds of electric vehicles such as electric cars, electric trains, electric boats, scooters, etc. Electric vehicles are grouped into three main categories as described in Table 1.

The hybrid vehicle uses gasoline and a small battery to supplement the standard internal combustion engine. Hybrids have a fuel efficiency that is increased by approximately 25% over traditional internal combustion engine vehicles. As a result, this vehicle type still has carbon emissions, but emits less than a traditional vehicle. A quick estimation calculation shows that a hybrid will emit approximately 23.1 kilograms of carbon dioxide for every 100 miles traveled compared to the traditional vehicle, which will emit 34 kilograms for the same travel distance (Roos, 2014). However, this comparison while in the absolute case dem-

Table 1. Comparison of types of electric vehicle

Car Type	Gasoline	Battery	Electric Charge
Hybrid	✓	✓	
Plug-in Hybrid	✓	✓	✓
Battery Electric Vehicle		✓	✓

onstrates that the hybrid is more environmentally friendly than a traditional internal combustion engine vehicle, does not account for the carbon footprint of producing a hybrid vehicle.

The Argonne National Laboratory conducted a life cycle analysis of hybrid and conventional vehicles. (Burnham, Wang, Wu, 2006). The results of the study show that the lifetime greenhouse gas emissions for conventional vehicles are much higher compared to hybrids. Simply stated, the internal combustion engine has an energy input of 500 grams per mile compared to the 340 grams per mile by the hybrid, which follows the same ratio as shown by Roos (2014). Higher energy input results in far greater lifetime greenhouse gas emissions.

Similarly, the plug-in vehicle is similar to the hybrid. It contains a larger battery pack, which can be charged from the power grid, regenerative braking and the gas engine. As a result, the plug-in hybrid still produces direct carbon emissions similar to the hybrid vehicle. Plug-in energy is not always cleaner than gasoline. For example, more than 45% of the electricity in the United States is generated by coal-powered plants (U.S. Energy Information Administration, 2010).

The battery electric vehicle is the immediate true "green" car due to its lack of tailpipe and resulting carbon emissions. The vehicle does not contain a combustion engine and must be plugged into the electric grid for recharging. However, the power plant producing the electricity may however emit greenhouse gases depending on the manufacturing of electricity similar to the plug-in vehicles. Different regions produce their electricity from different resources and methods and as a result the carbon footprint of an electric vehicle varies based on geographic (Boulanger et. al. 2011 & Shade of Green, 2014).

In this chapter, we focus on battery electric vehicles, which function solely on energy stored in rechargeable battery packs. Currently only a few BEVs exist on the market. Similar to other electric vehicles, BEVs use electric motors and motor controllers instead of internal combustion engines for propulsion. BEVs are different from plug-in hybrid vehicles which function partly on batteries and partly on gasoline similar to typical cars. A major difference aside from the use of gasoline that separates BEVs from hybrids is that BEVs plug into charging stations whereas hybrid vehicles cannot be externally charged.

CATEGORIZING BATTERY ELECTRIC VEHICLES

Current BEVs on the market are grouped into categories based on the potential maximum speed:

- **Low Speed:** Cars with a top speed of 37 miles per hour (mph) or less
- **City Speed:** Cars capable of reaching at least 37 mph but less than 62 mph
- **Highway:** Cars top speed above 65 mph.

Table 2 summarizes the charging times and driving ranges for a few currently available models for each of the 3 types of BEVs. While most of the vehicles in the current market generally require between 6 to 8 hours to completely charge using Level II charging through a North American standard 240-volt outlet power outlet, the driving range varies greatly between the three types of vehicles.

ADVANTAGES AND DISADVANTAGES OF ELECTRIC VEHICLES

There are several advantages of having EVs over typical internal combustion engine (ICE) based vehicles. These include energy efficiency, environmental friendliness and overall performance benefits.

Table 2. Examples of currently available BEVs for each category

Vehicle Name	Top Speed	Charging Time (Level 2 Charging, Defined in Table 4)	Driving Range	Market Release Date
Low Speed Vehicles				
Dynasty iT Sedan	25 mph	6 hours	30 miles	April 2001
GEM Car (Chrysler)	25 mph	6 - 8 hours	30 - 40 miles	April 1998
ZEV Smiley	31 mph	10 hours	75 miles	Spring 2007
City Speed Vehicles				
Citroën C1 ev'ie	60 mph	6 - 7 hours	60 - 70 miles	April 2009
NICE Mega City	40 mph	8 hours	60 miles	October 2006
Stevens Zecar	56 mph	6 - 8 hours	50 miles	March 2008
Highway Vehicles				
BMW i3	93 mph	4 hours	81 – 99 miles	2013
Nissan Leaf	93 mph	8 hours	73 miles	December 2010
Tesla Model S – 85 kWh	125 mph	3.5 hours	265 miles	2013

- *Energy Efficiency*: Electric motors convert 75% of the chemical energy from batteries to power the wheels versus ICEs, which only convert 20% of the energy stored in gasoline.
- *Environmentally Friendliness*: EVs do not emit any tailpipe pollutants. While the power plant producing the electricity may however emit some, sources of renewable energy (i.e. water, solar, wind) cause no pollution at all.
- *Performance Benefit*: EVs are quieter and provide smoother operation and stronger acceleration. They also require less maintenance than ICEs.

Despite advantages, EVs also have significant battery-related challenges associated to driving range and recharge time (Eberle and von Helmolt, 2010):

- *Driving Range*: Most EVs can only drive approximately 75 - 90 miles before needing to be recharged (Table 3). Gasoline based vehicles can travel over 300 miles before needing refueling. This lack of range by EVs is commonly referred to as "range anxiety" as drivers are fearful about not being able to drive to their destinations due to the limited driving ranges.

Table 3. Examples demonstrating range and charging limitations of currently available BEVs

Vehicle Name 2014 Model	Charging Time (Level 2 Charging, Defined in Table 4)	EPA Driving Range	Lithium Ion Battery Capacity	Manufactured Retail Suggested Price
BMW i3	3 hours	80 – 100 miles	35 kWh	$41,350
Chevrolet Spark EV	7 hours	82 miles	21.3 kWh	$26,685
Nissan Leaf	8 hours	84 miles	24 kWh	$28,980
Tesla S	3.5 hours	265 miles	85 kWh	$69,900
Ford Focus EV	4 hours	76 miles	23 kWh	$35,170
Honda Fit	3 hours	82 miles	20 kWh	$36,625

(EPA = United States Environmental Protection Agency)

- *Recharge Time*: Fully recharging batteries can take from 4 to 8 hours (Table 3). Using a method of "quick charge" to 80% capacity can take 30 minutes.
- Bulk and Weight: Battery packs are heavy and take up a considerable amount of vehicle space.

CURRENT BATTERY TECHNOLOGY

Any device that stores energy for later use is considered to be a battery. In electrical terms, a "battery" is limited to an electrochemical device that converts chemical energy into electricity with a galvanic cell.

Types of Batteries

BEV batteries are deep cycle, since they have to provide power over longer periods of time. Deep cycle batteries are designed to be regularly discharged to most of its capacity, usually between 50% - 80% depending on the manufacturer and construction of the battery. They are characterized by their relatively high power to weight ratio, energy to weight ratio, and energy density. For example, smaller and lighter batteries reduce the weight of the vehicle and in turn improve the performance. The maximum range of BEVs is due to current limitations in battery technologies such as the lower amount of specific energy (energy per unit mass) compared to fossil fuels.

Deep cycle batteries that are cycled down to having only 20% charge, have been shown to have a lower life span than those that maintain average cycles at 50% discharge (Serrao, et. al., 2011). Thus, there is a direct correlation between depth of discharge on the battery and the number of discharge cycles it can perform.

BEV batteries are commonly charged from the power grid. While most power for this is from domestic resources such as coal, hydroelectricity, nuclear, etc., renewable sources of energy may also be used such as solar, hydro, and wind. Certain manufacturers are investigating the possibility of using solar energy to recharge vehicles. The BMW i series has a solar carport as well as built in solar panels on the vehicle to reduce carbon emissions from traditional electricity generation (BMW i, 2014).

The capacity of the grid connection limits charging time. The normal household outlet provides between 1.5 kilowatts in countries with 110-volt supply to 3 kilowatts in countries with 240 volt supply. Higher power levels allow for faster charging, but there are constraints within the battery as most batteries do not accept charge greater than their charge rate since high charge rate has adverse effects on the discharge capabilities of the batteries.

In Germany, the Centre for Solar Energy and Hydrogen Research Baden-Württemberg, (ZSW) has developed lithium ion batteries that retain more than 85% of initial capacity after 10,000 complete charging and discharging cycles (with a complete charge and discharge cycle per hour). This indicates that batteries would be able to last upwards of 27.4 years. The power density for these batteries is also high (1,100 watts/kg) which indicates that EVs would have shorter charging times and better acceleration capabilities (ZSW, 2014).

Additionally, the charge rate (C) for batteries depends on the battery type. The charge rate (C-rate) is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. Therefore, in a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 100 Amps. Similarly, a 5C rate for this battery would be 500 Amps, and a C/2 rate would be 50 Amps. There are several batteries that exist currently on the market that allow for higher C-rates which would make it feasible to charge and discharge a battery quicker (Botsford and Szczepanek, 2009).

Battery Life

The lifespan of batteries vary with how it is used, maintained, and charged as well as temperature and other factors. Overcharging has negative consequences on batteries as does undercharging. Similarly over usage has the same type of negative consequence as under usage. Thus optimizing proper battery usage and charging is very important and necessary in maintaining long-term battery life. Batteries also have a life after the useful life in a car, so putting these on the other side of the electric vehicle supply equipment (EVSE) to load shift dense urban daytime commuter charging loads and other grid storage applications has been considered (Kelly-Detwiler, 2014).

SOLUTIONS FOR EXTENDING ELECTRIC VEHICLE RANGE

Several solutions for extending the range of electric vehicles are currently under consideration. These solutions include advancing both battery technologies as well as charging technologies.

Battery Technology Solutions

Methods to ameliorate some of these concerns involve designing larger capacity (kWh) and more efficient batteries to increase the driving range of the vehicles. However, this immediately correlates to an increased price of the BEV as batteries are currently the most expensive component to the vehicles. Additionally, a larger capacity battery does not necessarily correlate directly to an increase in operating distance. A larger capacity battery is usually one that weighs more as well, which in turn causes a vehicle to have a greater curb weight (Dhameja, 2001). This increase in weight can yield a higher consumption of energy per driving mile and as a result has a marginal increase in driving range (Dhameja, 2001). Still others are focusing on creating better batteries with larger charge-rates (C-rates) so the batteries would be able to charge and discharge quicker.

Quick Charge Solutions

Other research has focused on creating faster charging schema to recharge the batteries quicker. However, these charging systems require changes to current infrastructure to support the needs to provide power at such high levels quickly. Still, leading car manufacturers are taunting 20 to 30 minute recharge capabilities using quick charge stations.

An example of quick charging can be found on the Tesla Model S. The Supercharger by Tesla is the fastest charging station currently available. A 20-minute charge can fill the cars battery to half its capacity. Tesla has installed Superchargers throughout the United States and Europe. Over 100 charge stations are available worldwide as of May 2014. Their network of Superchargers in the United States makes it feasible for a vehicle to drive from California to New England for free through the use of these charge stations. Even with such drastic improvements over typical fast charge stations, Tesla still intends to develop further technology that would allow for vehicles to be fully recharged in 5 – 10 minutes (DailyTech, 2014). In recent days, Tesla is now sharing their fast charging patents with the world to accelerate EV adoption (Smith, 2014).

Standard Plug-In Charging

The most common solution to range anxiety is to install battery chargers similar to gas stations. This requires changing infrastructure to both build and install these charge stations and to ascertain that the grid in the desired area will be able to handle the additional load of multiple vehicles recharging at the same time. The main drawback aside from the need for infrastructure changes is the amount of time required for a vehicle to charge, which are currently orders of magnitude greater than the amount of time needed to currently refill a gas engine tank with fuel. Electric vehicle charging equipment is typically categorized into three types as summarized in Table 4. An example plug-in charging event for an EV truck is illustrated in Figure 1. The complete charging process may take more than six hours.

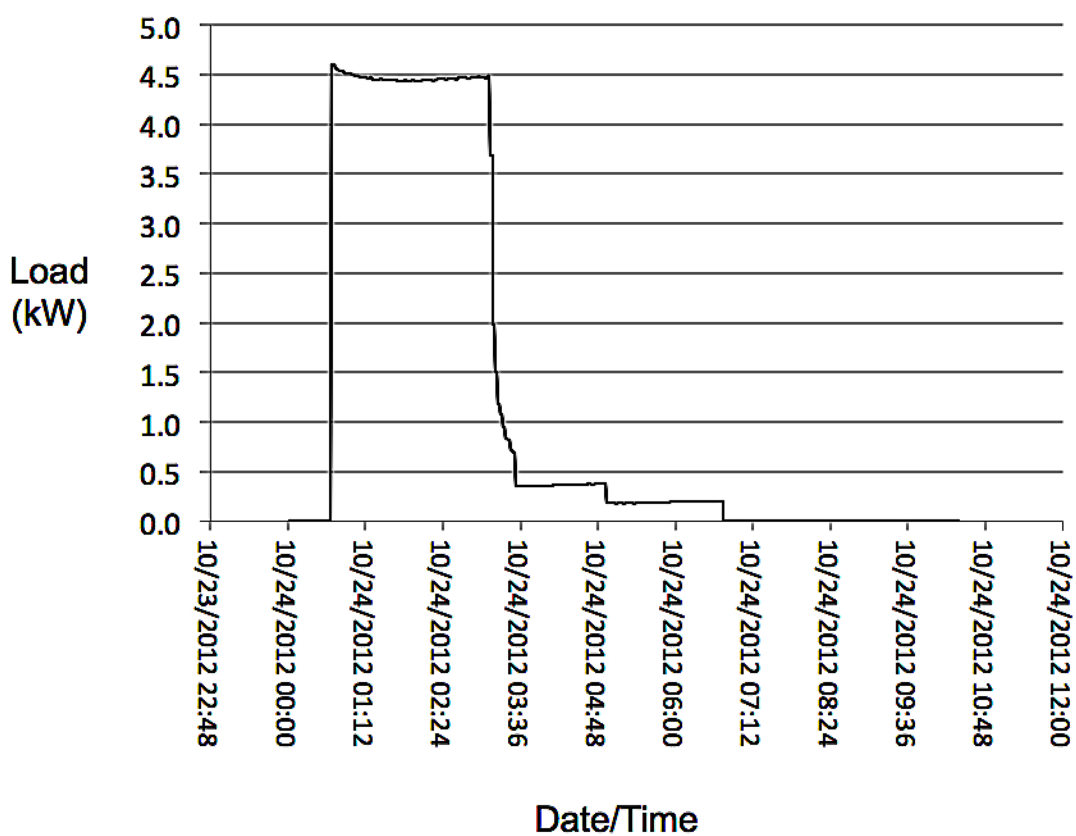
Swapping Solution

Battery swapping stations are another proposed method for recharging electric vehicles (Chen, et. al., 2013) (Ellis, et. al., 2013) (Worley and Klabjan, 2011). One noted leader in the industry, Better Place, recently announced that it would no longer be working in this domain (Motavalli, 2013). The company had raised over $850 million

Table 4. Currently available charging levels and necessary power supply requirements

Type	Charging Level	Power Supply	Charger Power	Charging Time
Normal	Level 1	120V, single phase, 12A	1.4 kW	16 hours
	Level 2	240V, single phase, 15A	3.3 kW	8 hours
		240V, single phase, 30A	6.6 kW	4 hours
Fast	Level 3	480 VDC, 3-phase	50kW	30 minutes

Figure 1. Example of plug-in charging event for an EV truck



from investors, in which the idea was to create a network of swapping stations that let electric vehicle drivers avoid long recharging times by simply swapping batteries through an automated process. This concept was being pursued in Israel, Denmark, Australia, China, and United States. American operations for Better Place were seen in localities such as Northern California and Hawaii. In Northern California (San Francisco and San Jose), Better Place had been commissioned to create all electric taxi fleets with swappable batteries.

Tesla is still investigating battery swapping as a solution to the range anxiety issue for their vehicles. Currently, the Tesla is designed such that its battery can be swapped in less than half the time it takes to refill a gas tank. However, the first Tesla battery swapping stations have not yet been implemented for public use.

The common problem with swapping batteries was the lack of uniformity in batteries. Therefore, finding an automatic method that could easily replace batteries for all types of EVs was not feasible until standardization occurs in EVs. Coupled with large infrastructure changes and heavy machinery that were needed to sustain the concept, the suggestion to swap batteries has not seen much popularity.

Another idea to increase effective driving range of electric vehicles was to have vehicles available on demand and to share EVs (King, et. al. (A) and (B)). This car-sharing program was much like that of hourly rental cars, where unused vehicles would be parked in a central location charging when not in use. This idea while useful for the adaptation of EVs is not sustainable as people own their vehicles and the concept of on demand and car sharing only works for rental vehicles and not personally owned vehicles.

Wireless Charging Solutions

There are many proposed methods for using wireless charging for electric vehicles. Wireless charging typically occurs through inductive power transfer (IPT) for the purposes of electric vehicles. IPT is a method in which electrical power is efficiently transferred between two objects without wires through an electromagnetic field. Several small household appliances are now available that utilize this technology such as rechargeable electric toothbrushes, cell phones, and remotes for gaming consoles. It is unaffected by dust, dirt, water, etc. and as a result has less wear and tear on electrical connections associated to the vehicle.

Currently, the most common application is to install wireless charge pads in homes. This application of wireless charge transfer offers the owner many benefits, from being able to utilize a program to offer guidance on smart charging to avoiding the hassle of physically plugging in the EV to the charging system. Still the disadvantage of this method is that it does not offer any additional driving range when the EV is being used on a day-to-day basis.

A current proposed method for using IPT for recharging EVs involves placing inductive charging strips on roadways to provide charge for BEVs driving on the street. Several research groups have suggested this method as a method to increase driving range of EVs, however have done little work to quantify the results from such a system (Lakshari, Shladover, Lechner 1986, Yilmaz, Buyukdegirmenci, Krein, 2012). The focus has been on the hardware and infrastructure changes needed to sustain this concept (Zhang, Wong, Chen 2011 and Zhang, et. al., 2014).

In South Korea, researchers at the Korean Advanced Institute of Science and Technology (KAIST), have developed an Online Electric Vehicle System (OLEV) designed to allow EVs travel longer distances with smaller batteries (Lee, et. al. 2010 and Ko, Jang, Jeong, 2012). KAIST has been able to successfully demonstrate their wireless roadway charging system with high transfer efficiencies (>70%) on a bus and SUV. However, a major disadvantage with this concept is still the need to alter existing infrastructure.

Another proposal involved installing wireless charging devices at traffic lights such that EVs can be charged while waiting at a traffic light (Mohrehkesh and Nadeem, 2011). The proposal further stated that intelligent transportation methods would need to be investigated to determine the best method for coordinating and extending stops at traffic lights to enable EVs to acquire charge. The method also suggests that EVs would be routed such that their frequency and duration at traffic lights are increased. This method not only requires changes to infrastructure but also adds a level of complexity by having all vehicles affected with the new traffic light schema. Additionally, there is no mention in the literature about the number of vehicles that can be serviced at one traffic light.

Alternative Charging Solutions

Several alternative methods have been proposed for wireless charging. While each method has its pros and cons, these methods currently have not gained much traction for vehicle charging. Among notable alternatives are: inductive coupling, laser, and strong electromagnetic resonance.

- *Inductive Coupling:* The inductive coupling works under the resonant coupling effect between coils of two LC circuits. The maximum efficiency is only achieved when transmitter and receiver are placed very close from each other. The cons of this method include the short range and the loss of efficiency as fast as the coils are separated.
- *Laser:* LaserMotive, a company that focuses on using laser technology to recharge batteries, flew a quadrocopter for 12.5 hours. This proof of principle experiment demonstrated an extension of the battery life by 150 times from its traditional 5 miles. Prior to this, in 2009, LaserMotive demonstrated the feasibility of their technology with transmission ranges over 1 kilometer.
- *Strong Electromagnetic Resonance*: In (Karalis et al., 2009) and (Kurs, 2007) introduced the method of wireless energy transfer via "Strong" electromagnetic resonance. This method uses the "strong" electromagnetic resonance phenomenon, achieving energy transfer efficiently at several dozens of centimeters.

VEHICLE-TO-VEHICLE WIRELESS CHARGING

While others have explored V2V applications, these were always proposed for stationary periods at parking locations using wired connections (Lui, Wu, Gao, 2013). We are the first to propose vehicle-to-vehicle (V2V) wireless charging (Dutta, 2013). The basic premise for our charge-sharing network is to have two vehicles wirelessly transfer charge between each other at coordinated rendezvous spots and/or traffic light intersections. Through the use of computer networking and communications algorithms we show the feasibility of such a scheme to increase the effective driving distance of an electric vehicle. The main advantage of our proposed solution is the lack of needing to change current roadway and grid infrastructures in metropolitan cities. Unlike installing charging or battery swapping stations, our method relies on vehicles serving as ad hoc moving charge stations that can offer charge to each other.

To make our concept feasible, the EVs will need to have specific hardware installed including inductive power transfer (IPT) devices as well as mechanisms that extend out of vehicles to minimize the distance between the two vehicles during the energy transfer. The feasibility of our network-based approach will be determined by modeling realistic average distances between opportunities for charge transfers by using real-world data. The frequency in which a BEV is able to receive charge units currently determines the success of the network given battery size and the amounts of energy that can be transferred in short intervals. Therefore, the average distance between charge transfers is a parameter that needs to decrease. This can be accomplished by increasing the number of vehicles participating and/or by communicating between vehicles to arrange rendezvous points.

Technological Feasibility

Current IPT technology is gaining traction in both the research and industrial markets. There are several startups, companies and research groups that are focusing their efforts to advance the overall technology. Table 5 summarizes examples from each of the sectors currently involved. The technological feasibility of this concept is dependent upon three key parameters of inductive charge transfer: efficiency, power level and safety.

Efficiency refers to the loss of energy during a charge transfer. Currently available technologies for IPT boast efficiencies well over 90%. The efficiency of the system is overall important to make sure that not too much energy is lost during a transfer. Since the system will have a limited amount of excess energy available; we need to ascertain that we can conserve as much energy as possible. Thus, if transfers are highly inefficient, then there may not be enough energy available in the system to support the total amount of charge needed by the participating vehicles.

Power levels for transfer are important to determine the amount of charge that can be transferred between vehicles in a 30 second stop at an intersection. We perform a quick back of the envelope calculation to determine the feasible rates of transfer for a Nissan Leaf with a standard total capacity 24 kWh battery. In order to transfer 5 units of charge in 30 seconds, we need to transfer 1.2 kWh in 30 seconds. Using a conservative efficiency of 90%, we assume that 10% is lost to heat, which indicates that we need to transfer 1.33 kWh in 30 seconds. Using a simple power calculation (Eq. 1), we note that we would need a transfer rate of 159.6 kW. While this is a relatively high transfer rate, we note that according to Table 5, there is already technology available that can sustain these rates.

$$Power = \frac{Energy}{time} = \frac{1.33kWh}{30\sec} = 159.6kW \tag{1}$$

Safety is a concern for charge transfers at such high power. For humans, the concern is about exposure to magnetic waves that are present dur-

Table 5. Examples of currently available IPT devices on the market along with their published specifications

	Name	Technology	Efficiency	Distance	Transfer Rates (In Sec)
Companies	Bombardier	PRIMOVE			Up to 200 kW
	Qualcomm	Qualcomm Halo			Up to 7 kW
	Siemens		>90%	15 cm	3.6 kW
Research Groups	ORNL		90 – 94%	25 cm	7 kW
	KAIST	OLEV	85%	20 cm	180 kW
	Stanford		>97%	6.5 feet	10 kW
Start-ups	Delphi			20 cm	3.3 kW
	EvaTran	Plugless Power	>90%	10 cm	3.3 kW
	WiTricity		>90%	15 – 20 cm	3.3 kW

ing a transfer. However, studies done on similar wireless charge transfers for buses at bus stops have not shown any issues for human exposure since the magnetic fields are well contained. Therefore, IPT has been shown to be safe to humans even at high transfer rates (Wu, Gilchrist, et. al., 2011). Similarly, determining battery safety is also important since the temperature will increase for the battery to accept the additional energy. We perform a quick calculation to determine whether the temperature increase during a charge transfer would affect the integrity of the battery and cause adverse events (i.e. battery explosion).

Using the earlier example of transfer to a Nissan Leaf, we estimate a lower bound of 10% of the transferred Joules becoming heat. Using equation 2, we obtain that 478,800 Joules of heat are produced. To calculate the amount that increases the battery temperature with the heat being spread equally, we apply equation 3. We assume that the mass of the battery is 293,930 grams (from literature) and that the specific heat capacity of Lithium Ion battery is 0.83 J/g C at the operating temperature of an electric vehicle. We note that the temperature of the battery simply increases 1.96 degrees Celsius during a charge transfer. This small increase of temperature is negligible and as a result does not pose any safety hazards for the technology.

$$E_{(j)} = energy * time \\ = 159.6kW * 30\sec = 4,788,000 Joules \tag{2}$$

$$Q = mc\Delta T \\ 478,800J = 293,930g * 0.83J / gC * \Delta T \\ \Delta T = 1.96C \tag{3}$$

Assumptions

We develop our model using simple heuristics for charge transfer and evaluate performance based on the number of cars that are able to reach their destination given varying driving distributions. The model is intended to serve as a proof of concept to determine whether IPT can increase the driving distance that a BEV can travel. To simplify the simulation, we assume:

- All cars enter the system with 100 units of charge, the capacity of a full battery. Units are dimensionless and 100 units correspond to the distance that can be driven on a fully charged battery.
- Charge and travel distance are normalized such that 1 unit charge results in a travel distance driven of 1 distance unit. (Many BEV's can travel 100 miles on a fully charged battery, so that 1 unit of distance is 1 mile.)
- A car does not need its excess remaining charge units upon reaching its destination.
- We assume lossless transfers since current transfer efficiencies are already greater than 90% (i.e. transfer efficiency is equal to 1).
- External factors that can cause a car to use more than 1 unit of charge to travel 1 unit of distance are not included in the model (i.e. cars are never stuck in traffic nor do they lose additional charge for using headlights, heating/air conditioning, radio, etc.).

Simulation Framework

Our vehicle-to-vehicle (V2V) charge-sharing network was developed in two main iterations. The first iteration was a simplified version developed in Matlab to demonstrate proof of principle, while the second version was developed in Java to serve as a more robust simulation model with more inputs and parameters. Figure 2 represents the advanced version of our model framework (Dutta, 2014).

Scheduling Rendezvous Points using Fisheye State Routing

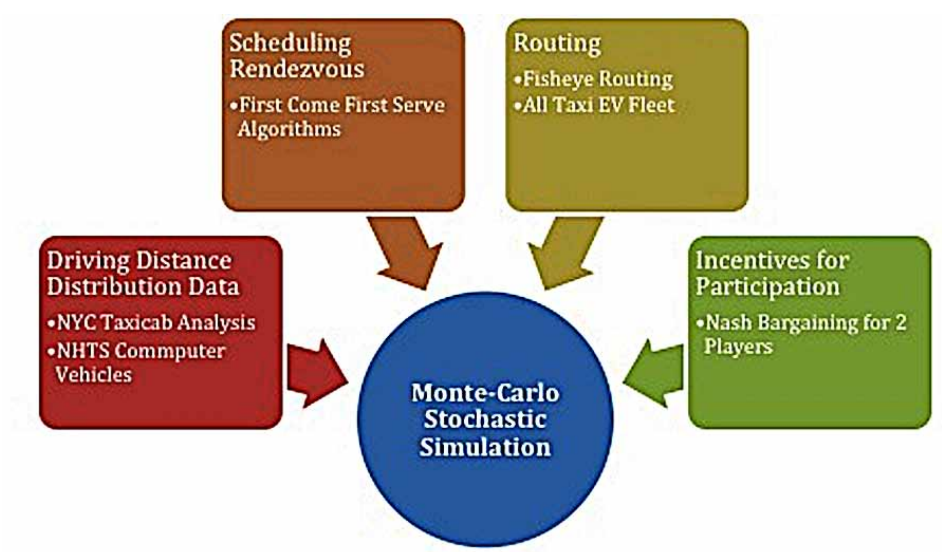
Common examples of scheduling rendezvous points involve public transit systems such as para-transit (Baker, Franz, Sweigart, 1993) and for private transportation systems such as package delivery (Rivers, 2002). In both these cases, one objective is to minimize the time that any passenger or package has to wait in order to reach their destination. The other objective is to reduce the number of delivery trucks and/or transit vehicles needed to accomplish the delivery and transportation of people and packages.

Our main objective is to retain excess charge in the system to increase the opportunities for vehicles needing charge to acquire charge in order to reach their destinations. Using GPS, we know the start, node i, and ending, node j, points for all vehicles entering and exiting the system.

We propose a novel application of fisheye state routing (FSR) to coordinate the meeting of vehicles at rendezvous points to exchange charge (Jaap, Bechler, Wolf, 2005). The FSR approach translates to maintaining accurate distance and path quality information about the immediate neighborhood of a node, with progressively less detail as the distance increases (Pei, Gerla, Chen 2000 and Johansson, et. al., 2004).

For our case, FSR is useful since we have the most information about vehicles that are closest to each other at a given time iteration. It is harder to predict with reasonable accuracy the arrival time for a vehicle to a destination that is further away given driving conditions. Therefore, to minimize both charge consumed and time for the vehicles that are set to rendezvous, we want to find the optimal pairing and routing that requires the least amount of deviation from original routing for both vehicles.

Figure 2. Inputs for our vehicle-to-vehicle charge sharing Monte-Carlo stochastic simulation. The model has been created to be sensitive to several parameters, which can be adjusted to reflect conditions in different geographic areas.



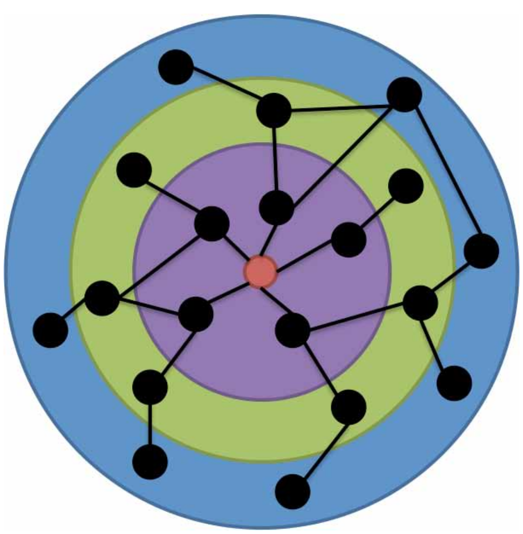
We define our fisheye scope based on a "desperation factor" with a first-come-first-serve (FCFS) methodology for the vehicle needing charge. This "desperation factor" determines the radius of the scope that the vehicle will communicate within to find a feasible car for charge transfer (Figure 3). Results from our simulations can be founds in papers listed under the additional reading sections. Overall, we demonstrate an extension of EV range by over 150%.

Offering Incentives using Game Theory Methods

In order to encourage participation in our charge-sharing network, we model one method for offering incentives through a pricing strategy. Our approach is to determine the bargaining that would occur if only two system participants are exchanging charge through Nash Bargaining.

Cars that require charge (c < d) in order to successfully reach their goal are referred to as buyers while cars that have excess charge (c > d) are referred to as sellers. Buyers want to purchase units of charge from sellers at the lowest price possible while sellers want to maximize their revenue. Incentives for participation are offered to encourage participation in the system. The buyer's incentive is to reach its destination without needing to stop for recharging, while the seller's incentive is to earn money on route to a destination.

Figure 3. Fisheye scopes for vehicles. The smallest radii occurs when cars are least desperate for charge and expands until the radii, r, approaches the number of units of charge remaining for the vehicle at critical point.



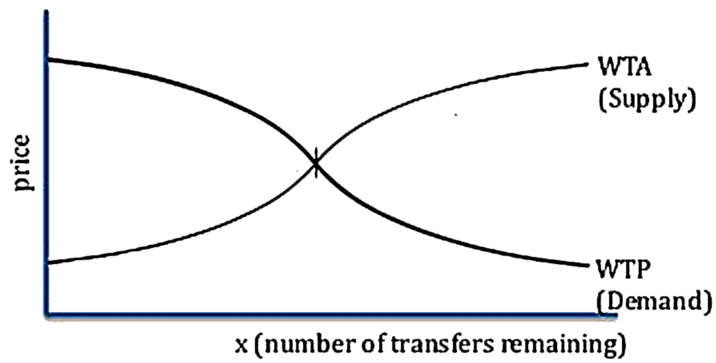
In each transaction, two cars, one buyer and one seller, determine a price at which the charge transaction will occur if its possible. They both have a price that they are willing to pay/receive for each unit charge, referred to as buyer's Willingness to Pay (WTP) and seller's Willingness to Accept (WTA). We model WTP and WTA as logistic functions (Figure 4). Since logistic functions have two horizontal asymptotes, we are able to set the lower asymptote at the minimum price that a unit charge is worth (the market value) and the maximum price that one is willing to pay or can receive for a unit charge (i.e. cost of failure for buyer and governmental regulations for seller).

Nash Bargaining theory assumes there is one buyer and seller. The seller values the trade less than the buyer such that WTP ≥ WTA. This is because the seller only loses potential income from the transaction if it is unable to sell the excess charge but does not face issues with reaching its destination. However, if WTP < WTA, no trade is possible. We determine the price, p, the buyer and seller agree upon for the transaction assuming that WTA ≠ WTP using the Nash Bargaining Solution (NBS) from cooperative game theory.

Nash Bargaining Formulation and Solution

We assume that at each intersection, only two cars will be involved in a charge transfer: one buyer, and one seller. The seller is willing to sell with cost, WTA and the buyer places a value on the unit of charge, WTP. We assume that as long as WTP > WTA, the transaction will occur. Our

Figure 4. Example of WTA and WTP pricing using logistic functions



problem is to determine at what price, p, will the unit of charge be sold at. We define the buyers and sellers utility as shown in equations 7 and 8, respectively. If no transaction occurs, then both the buyer and seller utility are 0.

Set *S* is the set of all feasible outcomes where the outcomes for the players are denoted by $\left(u_1, u_2\right)$. The buyer's utility is u_2 (eq. 4) and the seller's utility is u_2 (eq. 5). If no price agreement is reached, then both seller and buyer are at a disagreement point (0, 0).

$$u_1 = U_B(WTP - Price) = (WTP - Price) \tag{4}$$

$$u_2 = U_S(\Pr ice - WTA) = (\Pr ice - WTA) \tag{5}$$

The bargaining solution will be given by single point $\left(u_1^*, u_2^*\right)$ that satisfies the following assumptions:

- **Individual rationality:** $\left(u_1^*, u_2^*\right) \geq 0$. Simply stated, the bargaining solution must be at least as good for each player as what they would get from no agreement.
- **Feasibility:** $\left(u_1^*, u_2^*\right)$ must be in the set *S*, which basically states that we cannot allocate something that is not available to be given out.
- **Pareto optimality:** This means that there can't exist any other proposed bargaining solution that provides a better solution than $\left(u_1^*, u_2^*\right)$.
    - Independence of irrelevant alternatives
    - Independence of linear transformations
    - Symmetry.

The value added by a trade, M, is determined when the buyer and seller agree to a trade and is determined by equation 6. Consequently, we can calculate the value added to the buyer, U_B, and seller, U_S, using equations 7 and 8, respectively.

$$M = WTA - WTP \tag{6}$$

$$U_B = WTP - Price \tag{7}$$

$$U_S = Price - WTA \tag{8}$$

When a disagreement occurs, we assign a value referred to as the best alternative to negotiated agreement (BATNA). If both players in a 2-player bargaining game disagree on how to divide M, then each receives their disagreement value. Let D_b represent the disagreement player for the buyer and D_s represent the disagreement value for seller. We set our disagreement to 0, since if no transaction occurs then both the buyer and seller receive no utility.

$$U_s\left(Price - WTA\right)$$
$$= \left(Price - WTA\right)U_s\left(Price - WTA\right)$$
$$= \left(Price - WTA\right)$$

The bargaining problem is a pair, *B=(U,d)*, such that *U* is the set of utility pairs that can be obtained as p varies between WTA and WTP. The element of *U* is pair $u = \left(u_1, u_2\right)$. If $u \in Uu \in U$, then buyer gets utility u_1 and seller gets utility u_2. As noted before, the disagreement point is (0,0). Thus, if no agreement is reached, then buyer and seller get utility 0. The Nash Solution function will tell us what utility the buyer and the seller receive, and hence the price at which the object is traded.

To find the solution, we determine the Nash Product (eq. 9) and identify the price, p, which maximizes the equation. We find feasible utilities in the pair $\left(\left(Price - WTA\right), \left(WTP - Price\right)\right)$ as p varies in interval (WTA, WTP). We maximize by choice of p in constraint: $WTA \le Price \le WTP$, we find the NBS is determined by equation 10, since p satisfies the constraint $WTA \le Price \le WTP$.

Nash Product

$$= (Price - WTA)^{\alpha}(WTP - Price)^{\beta}$$

$$price = \frac{WTA + WTP}{2} \tag{10}$$

Future Work on Vehicle-to-Vehicle Wireless Charging

Future work is twofold. While we have created an extensive robust model to show the feasibility of such as a system, the implementation of such a model is crucial. Certain parameters in our models are estimations for human behavior and need, and as a result the model can only estimate these.

The physical implementation of an IPT system that can transfer charge between vehicles is necessary. We have hypothetically described how these devices would function. However, actual implementation is necessary to determine the new application of this technology.

Future work can also be useful in extending our charge transfer framework to become more robust, sensitive to various parameters, and addition of parameters to better model a situation. We identify a number of areas for future work, which include the development of better heuristics to determine charge transfer. Some specific ideas for possible future work are discussed in this chapter along

Table 6. Differences between structured and unstructured fleet vehicles

	Structured	Unstructured
Schedule	Yes	No
Network path	Yes	No
Example	FedEx, UPS, MTA	Taxicabs, Rental Cars, Commuter Vehicles

with potential framework ideas for pursuing the development of these areas.

One possible extension is to explore the addition of structured and semi-structured fleet vehicles to the model. In the current framework, we focus our analysis to unstructured fleet vehicles that include commuter vehicles and taxicabs. Fleet vehicles are defined as groups of vehicles that are owned or leased by a business as opposed to an individual or family. Types of fleet vehicles range from cars to vans to trucks, depending on the need of the company. Multiple drivers, multiple paths, or any combination of the two can use any single vehicle in a fleet system. In essence, fleet vehicles can be thought of as moving micro-grids or networks with nodes and parameters. Fleets of vehicles can be clustered into groups: structured and unstructured fleet vehicles (Table 6). Each of the types of fleet vehicles serves very different functions.

REFERENCES

Baker, H. M., Franz, L. S., & Sweigart, J. R. (1993). Coordinated transportation systems: An alternative approach to traditional independent systems. *European Journal of Operational Research*, *66*(3), 341–352. doi:10.1016/0377-2217(93)90222-9

BMW i. Malibu (Solar Carport Demo). (n.d.). *World Team Now*. Retrieved June 14, 2014, from http://worldteamnow.org/blog/2014/05/07/bmw-i-malibu-solar-carport-demo/

Botsford, C., & Szczepanek, A. (2009). Fast charging vs. slow charging: Pros and cons for the new age of electric vehicles. EVS24, Stavanger, Norway.

Boulanger, A. G., Chu, A. C., Maxx, S., & Waltz, D. L. (2011). Vehicle electrification: Status and issues. *Proceedings of the IEEE*, *99*(6), 1116–1138. doi:10.1109/JPROC.2011.2112750

Burnham, A., Wang, W., & Wu, Y. (2006, November) Development and Application of GREET 2.7 - The Transportation Vehicle Cycle Model. Energy Systems Division, Argonne National Laboratory. Retrieved May 4, 2014, from http://www.transportation.anl.gov/pdfs/TA/378.pdf

Casey, T. (2014, January 9). Ford Packs More Solar Power Storage Punch Into MyEnergi Lifestyle. CleanTechnica. Retrieved June 15, 2014, from http://cleantechnica.com/2014/01/09/ford-adds-solar-power-storage-myenergi-lifestyle/

Chen, Z., Liu, N., & Xiao, X. (2013, May). Energy exchange model of PV-based battery switch stations based on battery swap service and power distribution. In Energytech, 2013 IEEE (pp. 1-6). IEEE. doi:10.1109/VPPC.2013.6671681

DailyTech - Tesla Building Tech to Fully Charge EVs in Just 5 Minutes. (n.d.). *DailyTech - Tesla Building Tech to Fully Charge EVs in Just 5 Minutes*. Retrieved June 14, 2014, from http://www.dailytech.com/Tesla+Building+Tech+to+Fully+Charge+EVs+in+Just+5+Minutes/article31990.htm

Dhameja, S. (2001). *Electric vehicle battery systems*. Newnes.

Dutta, P. (2013, July). Use of inductive power transfer sharing to increase the driving range of electric vehicles. In *Power and Energy Society General Meeting (PES), 2013 IEEE* (pp. 1-5). IEEE. doi:10.1109/PESMG.2013.6672635

Dutta, P. (2014, July) Charge Sharing Model using Inductive Power Transfer to Increase Feasibility of Electric Vehicle Taxi Fleets. In *Power and Energy Society General Meeting (PES), 2014*. IEEE. doi:10.1109/PESGM.2014.6939294

Eberle, U., & von Helmolt, R. (2010). Sustainable transportation based on electric vehicle concepts: A brief overview. *Energy & Environmental Science*, *3*(6), 689–699. doi:10.1039/c001674h

Ellis, R., Fackrell, C., Gordon, T., Lamb, P., Morris, J. E., & Kawasaki, C. (2013, August). Battery recharging and testing swap stations. In *Technologies for Sustainability (SusTech), 2013 1st IEEE Conference on* (pp. 208-211). IEEE. doi:10.1109/SusTech.2013.6617322

Harris, A. (2009). Charge of the electric car (electric vehicles). *Engineering & Technology*, *4*(10), 52–53. doi:10.1049/et.2009.1009

Jaap, S., Bechler, M., & Wolf, L. (2005). Evaluation of routing protocols for vehicular ad hoc networks in typical road traffic scenarios. *Proc of the 11th EUNICE Open European Summer School on Networked Applications*, 584-602.

Johansson, E., Persson, K., Skold, M., & Sterner, U. (2004, May). An analysis of the fisheye routing technique in highly mobile ad hoc networks. In Vehicular Technology Conference, 2004. VTC 2004-Spring. 2004 IEEE 59th (Vol. 4, pp. 2166-2170). IEEE. doi:10.1109/VETECS.2004.1390657

Karalis, A., Joannopoulos, J. D., & Soljačić, M. (2008). Efficient wireless non-radiative mid-range energy transfer. *Annals of Physics*, *323*(1), 34–48. doi:10.1016/j.aop.2007.04.017

Kelly-Detwiler, P. (2014, March 18). The Afterlife For Electric Vehicle Batteries: A Future Source Of Energy Storage? Forbes. Retrieved June 15, 2014, from http://www.forbes.com/sites/peterdetwiler/2014/03/18/the-afterlife-for-electric-vehicle-batteries-a-future-source-of-energy-storage/

King, C., Griggs, W., Wirth, F., Quinn, K., & Shorten, R. (2013). Alleviating a form of electric vehicle range anxiety through On-Demand vehicle access. arXiv preprint arXiv:1312.5939.

King, C., Griggs, W., Wirth, F., & Shorten, R. (2013, June). Using A Car Sharing Model To Alleviate Electric Vehicle Range Anxiety. In he 16th Yale Workshop on Adaptive and Learning Systems.

Ko, Y. D., Jang, Y. J., & Jeong, S. (2012, August). Mathematical modeling and optimization of the automated wireless charging electric transportation system. In Automation Science and Engineering (CASE), 2012 IEEE International Conference on (pp. 250-255). IEEE. doi:10.1109/CoASE.2012.6386482

Kurs, A. (2007). Power transfer through strongly coupled resonances (Doctoral dissertation, Massachusetts Institute of Technology).

Lashkari, K., Shladover, S. E., & Lechner, E. H. (1986). Inductive power transfer to an electric vehicle. In International Electric Vehicle Symposium (8th: 1986: Washington DC).

Lee, S., Huh, J., Park, C., Choi, N. S., Cho, G. H., & Rim, C. T. (2010, September). On-Line Electric Vehicle using inductive power transfer system. In Energy Conversion Congress and Exposition (ECCE), 2010 IEEE (pp. 1598-1601). IEEE. doi:10.1109/ECCE.2010.5618092

Liu, C., Chau, K. T., Wu, D. I. Y. U. N., & Gao, S. H. U. A. N. G. (2013). *Opportunities and Challenges of Vehicle-to-Home*. Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies.

Mohrehkesh, S., & Nadeem, T. (2011, October). Toward a wireless charging for battery electric vehicles at traffic intersections. In Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on (pp. 113-118). IEEE. doi:10.1109/ITSC.2011.6083137

Motavalli, J. (2013, June 1). Fallout From Failure of Battery Swap Plan. The New York Times. Retrieved June 14, 2014, from http://www.nytimes.com/2013/06/02/automobiles/fallout-from-failure-of-battery-swap-plan.html?_r=0

Pei, G., Gerla, M., & Chen, T. W. (2000). Fisheye state routing: A routing scheme for ad hoc wireless networks. In Communications, 2000. ICC 2000. 2000 IEEE International Conference on (Vol. 1, pp. 70-74). IEEE.

Rivers, C. (2002). Coordination in vehicle routing (Doctoral dissertation, Ph. D. thesis, Massey University, Palmerston North, New Zealand).

Roos, D. (2010, December 6). Does hybrid car production waste offset hybrid benefits? HowStuffWorks. Retrieved June 14, 2014, from http://science.howstuffworks.com/science-vs-myth/everyday-myths/does-hybrid-car-production-waste-offset-hybrid-benefits2.htm

Serrao, L., Onori, S., Sciarretta, A., Guezennec, Y., & Rizzoni, G. (2011, June). Optimal energy management of hybrid electric vehicles including battery aging. In *American Control Conference (ACC)*, 2011 (pp. 2125-2130). IEEE. doi:10.1109/ACC.2011.5991576

Shade of Green. (2014, May 4) Shade of Green: Electric Cars' Carbon Emissions Around the Globe. Shrink that Footprint. Retrieved May 4, 2014, from http://shrinkthatfootprint.com/wp-content/uploads/2013/02/Shades-of-Green-Full-Report.pdf

Shah, J., Nielsen, M., Reid, A., Shane, C., Mathews, K., Doerge, D., . . . Sarkar, S. (2014, March). Cost-optimal, robust charging of electrically-fueled commercial vehicle fleets via machine learning. In Systems Conference (SysCon), 2014 8th Annual IEEE (pp. 65-71). IEEE. doi:10.1109/SysCon.2014.6819237

Smith, D. (2014, June 9). Elon Musk May Give Away Its Tesla Supercharger Patents To Spur Electric Car Development. Business Insider. Retrieved June 14, 2014, from http://www.businessinsider.com/elon-musk-tesla-supercharger-patents-2014-6

Tauber, L. A. (1995, October). Viability and economics of building or purchasing, driving, and maintaining an electric car. In Northcon 95. I EEE Technical Applications Conference and Workshops Northcon95 (pp. 400-405). IEEE. doi:10.1109/NORTHC.1995.485104

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2010, November). Electric Power Monthly. Retrieved June 14, 2014, from http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html

Worley, O., & Klabjan, D. (2011, September). Optimization of battery charging and purchasing at electric vehicle battery swap stations. In *Vehicle Power and Propulsion Conference (VPPC)*, 2011 IEEE (pp. 1-4). IEEE. doi:10.1109/VPPC.2011.6043182

Wu, H. H., Gilchrist, A., Sealy, K., Israelsen, P., & Muhs, J. (2011, May). A review on inductive charging for electric vehicles. In Electric Machines & Drives Conference (IEMDC), 2011 IEEE International (pp. 143-147). IEEE. doi:10.1109/IEMDC.2011.5994820

Yilmaz, M., Buyukdegirmenci, V. T., & Krein, P. T. (2012, June). General design requirements and analysis of roadbed inductive power transfer system for dynamic electric vehicle charging. In *Transportation Electrification Conference and Expo (ITEC)*, 2012 IEEE (pp. 1-6). IEEE. doi:10.1109/ITEC.2012.6243497

Zhang, W., Wong, S., Tse, C., & Chen, Q. (2014). An Optimized Track Length in Roadway Inductive Power Transfer Systems. *Emerging and Selected Topics in Power Electronics, IEEE Journal of, 99*.

Zhang, W., Wong, S. C., Tse, C. K., & Chen, Q. (2011, September). A study of sectional tracks in roadway inductive power transfer system. In Energy Conversion Congress and Exposition (ECCE), 2011 IEEE (pp. 822-826). IEEE. doi:10.1109/ECCE.2011.6063855

ZSW engineers build lithium-ion battery able to last for 27 years. (n.d.). *ZSW engineers build lithium-ion battery able to last for 27 years*. Retrieved June 14, 2014, from http://phys.org/news/2013-06-zsw-lithium-ion-battery-years.html

ADDITIONAL READING

Basset, P., Kaiser, A., Legrand, B., Collard, D., & Buchaillot, L. (2007). Complete system for wireless powering and remote control of electrostatic actuators by inductive coupling. Mechatronics, IEEE/ASME Transactions on,12(1), 23-31.

Bayram, I. S., Michailidis, G., Devetsikiotis, M., Granelli, F., & Bhattacharya, S. (2012). Smart vehicles in the smart grid: Challenges, trends, and application to the design of charging stations. In *Control and Optimization Methods for Electric Smart Grids* (pp. 133–145). Springer New York. doi:10.1007/978-1-4614-1605-0_6

Deilami, S., Masoum, A. S., Moses, P. S., & Masoum, M. A. (2011). Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. Smart Grid. *IEEE Transactions on*, *2*(3), 456–467.

Dutta, P. (2013, December). Coordinating rendezvous points for inductive power transfer between electric vehicles to increase effective driving distance. In Connected Vehicles and Expo (ICCVE), 2013 International Conference on(pp. 649-653). IEEE. doi:10.1109/ICCVE.2013.6799872

Dutta, P. (2014, July) Charge Sharing Model using Inductive Power Transfer to Increase Feasibility of Electric Vehicle Taxi Fleets. In *Power and Energy Society General Meeting (PES)*, 2014. IEEE. doi:10.1109/PESGM.2014.6939294

Dutta, P., Boulanger, A., & Anderson, R. (2014, July). Understanding the Usage of NYC Taxicabs for Vehicle Electrification in a Large Metropolitan Area. In NSF Workshop on Big Data and Urban Informatics 2014 (BDUIC). NSF.

Fang, X., Misra, S., Xue, G., & Yang, D. (2012). Smart grid—the new and improved power grid: A survey. *IEEE Communications Surveys and Tutorials*, *14*(4), 944–980. doi:10.1109/SURV.2011.101911.00087

Guille, C., & Gross, G. (2009). A conceptual framework for the vehicle-to-grid V2G) implementation. *Energy Policy*, *37*(11), 4379–4390. doi:10.1016/j.enpol.2009.05.053

Hosseini, S. S., Badri, A., & Parvania, M. (2012, September). The plug-in electric vehicles for power system applications: The vehicle to grid (V2G) concept. In Energy Conference and Exhibition (ENERGYCON), 2012 IEEE International (pp. 1101-1106). IEEE.

Kempton, W., & Tomić, J. (2005). Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. *Journal of Power Sources*, *144*(1), 280–294. doi:10.1016/j.jpowsour.2004.12.022

Low, Z. N., Chinga, R. A., Tseng, R., & Lin, J. (2009). Design and test of a high-power high-efficiency loosely coupled planar wireless power transfer system. Industrial Electronics. *IEEE Transactions on*, *56*(5), 1801–1812.

Pang, C., Dutta, P., & Kezunovic, M. (2012). BEVs/PHEVs as dispersed energy storage for V2B uses in the smart grid. Smart Grid. *IEEE Transactions on*, *3*(1), 473–482.

Richardson, D. B. (2013). Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. *Renewable & Sustainable Energy Reviews*, *19*, 247–254. doi:10.1016/j.rser.2012.11.042

Su, W., Eichi, H., Zeng, W., & Chow, M. Y. (2012). A survey on the electrification of transportation in a smart grid environment. Industrial Informatics. *IEEE Transactions on*, *8*(1), 1–10.

Wan, J., Li, D., Zou, C., & Zhou, K. (2012, October). M2M communications for smart city: an event-based architecture. In Computer and Information Technology (CIT), 2012 IEEE 12th International Conference on (pp. 895-900). IEEE

Wang, C. S., Stielau, O. H., & Covic, G. A. (2005). Design considerations for a contactless electric vehicle battery charger. Industrial Electronics. *IEEE Transactions on*, *52*(5), 1308–1314.

World Team Now. (n.d.). World Team Now. Retrieved June 14, 2014, from http://www.worldteamnow.org/

KEY TERMS AND DEFINITIONS

Electric Vehicle Supply Equipment: (EVSE) Defined as the conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle by the 1996 NEC and California Article 625.

Machine-to-Machine: (M2M) Broad term that refers to technologies that allow both wireless and wired systems to communicate with other devices of the same type.

Original Equipment Manufacturer: (OEM) In the context of automotive parts, designates a replacement part made by the same manufacturer as the original part.

Vehicle-to-Building: (V2B) Describes a system in which electric vehicles can communicate with a building to sell demand response services by either delivering electricity into the building or by throttling their charging rate.

Vehicle-to-Grid: (V2G) Describes a system in which electric vehicles can communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate.

Vehicle-to-Vehicle: (V2V) Describes a system in which electric vehicles can communicate to each other to sell demand response services by delivering electricity to each other.

Chapter 11
New Transportation Systems for Smart Cities

Christos G. Cassandras
Boston University, USA

ABSTRACT

Poor traffic management in urban environments is responsible for congestion, unnecessary fuel consumption and pollution. Based on new wireless sensor networks and the advent of battery-powered vehicles, this chapter describes three new systems that affect transportation in Smart Cities. First, a Smart Parking system which assigns and reserves an optimal parking space based on the driver's cost function, combining proximity to destination and parking cost. Second, a system to optimally allocate electric vehicles to charging stations and reserve spaces for them. Finally, we address the traffic light control problem by viewing the operation of an intersection as a stochastic hybrid system. Using Infinitesimal Perturbation Analysis (IPA), we derive on-line gradient estimates of a cost metric with respect to the controllable green and red cycle lengths and iteratively adjust light cycle lengths to improve (and possibly optimize) performance, as well as adapt to changing traffic conditions.

INTRODUCTION

The term "Smart City" is used to capture the overall vision of an urban environment with well-managed processes such as traffic control and energy distribution; safer and more efficient services such as parking or emergency response; and a new generation of innovative services yet to be developed. From a technological point of view, at the heart of a Smart City is a cyber-physical infrastructure with physical elements (e.g. roads, vehicles, power lines) which are continuously monitored through various sensors to observe, for instance, air/water quality, traffic conditions, occupancy of parking spaces, the structural health of bridges, roads and buildings, as well as the location and status of city resources including transportation vehicles, police cars, police officers, and municipal workers. The data collected need to be securely communicated (mostly wirelessly) to information processing and control points. These data may be shared and the control points can cooperate to generate good (ideally, optimal) decisions regarding the safe operation of these physical elements (e.g. vehicles guided through the city). It is important to emphasize that what ultimately makes the city

DOI: 10.4018/978-1-4666-8282-5.ch011

"smart" is not simply the availability of data but the process of "closing the loop", consisting of sensing, communicating, decision making, and actuating. Figure 1 is a high-level illustration of this process, which must take place while taking into account important issues of privacy, security, safety and proper energy management necessitated by the wireless nature of most data collection and actuation mechanisms involved.

In this chapter, our focus is on transportation aspects of urban settings and on new developments which promise to revolutionize how vehicles operate in a Smart City and how overall traffic is managed. At any given time, hundreds of thousands of vehicles are in constant motion through the roadway networks associated with any large urban area. Based on the 2011 Urban Mobility Report, the cost of commuter delays has risen by 260% over the past 25 years and 28% of US primary energy is now used in transportation. Congestion in such traffic networks is estimated to be responsible for 20% of fuel consumption in any significant urban area. A major source of frustration for our inability to improve traffic conditions is the realization that, even if we could determine a theoretical optimal operation point, there are extremely few controls currently allowing us to attain this point: they are mostly simple signaling schemes (traffic lights) and economic incentive mechanisms (tolls, speeding fines). At the heart of the problem is one of the well-known folk-principles from game theory: when a player (driver) lacks information about the behavior of other players (drivers), poor decisions are made

Figure 1. Cyber-physical infrastructure for a Smart City

(Braess et al., 2005). Consequently, even if a driver is "smart" and makes use of sophisticated data about the state of the system, his/her decisions may be driver-optimal, but not system-optimal.

In fact, poor or inadequate traffic management in urban environments is responsible not only for congestion, causing a significant waste of time and frustration, but also unnecessary fuel consumption and environmental harm through pollution. As an example, it is estimated that 30% of traffic congestion in an urban downtown area is caused by vehicles cruising for a parking space and it takes a driver an average of 7.8 minutes to find one (Arnott et al., 2005). It has also been reported that over one year in a small Los Angeles business district, cars cruising for parking created the equivalent of 38 trips around the world, burning 47,000 gallons of gasoline and producing 730 tons of carbon dioxide (Shoup, 2005). In addition, the inefficiency of existing traffic light controllers is well established, as evidenced by the common occurrence of vehicle backlogs forming in a road subjected to a long red cycle while no traffic is present in a cross road competing for the same intersection. There are two major technological developments which provide tremendous opportunities to develop new transportation systems for a Smart City, leading to reduced pollution and fossil fuel consumption in addition to a vastly improved quality of service for drivers and pedestrians alike. First, the new sensors and wireless networks connecting them provide the capability to make real-time data available for urban traffic conditions. For example, the state of a parking space (either on-street or off-street) can be readily detected and used to assign such spaces to drivers and even reserve them. Second, the advent of battery-powered vehicles, including Electric Vehicles (EVs), provides an opportunity to drastically reduce harmful emissions and conserve energy. Naturally, introducing these technologies into urban environments entails challenges which need to be overcome in order to deliver the expected benefits. These challenges may not only be technological in nature, but also socio-economic, as new policies and incentive structures need to be introduced in order to lead to the effective adoption of the new transportation systems proposed.

In the remainder of the chapter, we will discuss three new systems affecting transportation in Smart Cities. First, we will describe a Smart Parking system. We will then explain how the key ideas used in Smart Parking can be applied to a system for optimally allocating Electric Vehicles (EVs) to charging stations and reserving spaces for them. Finally, we will present a new approach for adaptively controlling traffic lights, leading to improved traffic control in an urban setting.

A Smart Parking (SP) System

As already mentioned, as much as 30% of traffic in urban settings is estimated to be due to vehicles searching for parking. This has motivated considerable work in studying parking behavior and improving parking efficiency. Various models aimed at understanding how drivers make parking choices have been developed over the past two decades (e.g. Thompson & Richardson, 1998; Young et al., 1991), while traffic authorities in many cities have developed so-called Parking Guidance and Information (PGI) systems for better parking management. PGI systems present drivers with dynamic information on parking within controlled areas and direct them to vacant parking spaces. Parking information may be displayed on variable-message signs (VMS) at major roads, streets, and intersections, or it may be disseminated through the Internet (Griffith, 2000; Streetline, 2012; Teodorovic & Lucic, 2006). PGI systems are based on parking space monitoring, typically through the use of sensors placed in the vicinity of parking spaces for vehicle detection (Mimbela & Klein, 2000). However, using PGI systems, system-wide reductions in travel time and vehicle benefits have been found to be relatively small (Thompson & Richardson, 1998; Waterson et al., 2001). Building upon the objectives of PGI systems, several reservation-based parking systems have also emerged, allowing drivers to obtain parking information before or during a trip, and reserve a parking space (Hodel & Cong, 2003; Rodier & Shaheen, 2010; Tsai & Chu, 2012). In addition, traffic congestion can also be reduced by controlling the parking price (Chou et al., 2008; Teodorovic & Lucic, 2006). For example, in San Francisco (SFPark) there are already time-dependent or demand-dependent parking fees to achieve the right level of parking availability in different areas (SFPark, 2012).

Although current parking guidance systems increase the probability of finding vacant parking spaces, they have serious shortcomings (Geng & Cassandras, 2013). First, drivers may not actually find vacant parking spaces by merely following the guidance. In essence, such systems change driver behavior from searching to competing for parking: more drivers go toward the same available parking spots and it is possible that none are free by the time some drivers arrive, thus forcing replanning and competition for other spots. Although smartphone applications exist for drivers to check real-time parking information using their mobile phones, there are also safety issues associated with drivers watching parking updates while driving. Second, even if a driver is successfully guided to a parking space, such a system increases the probability of finding any parking space at the expense of missing the opportunity for a better space. For example, a driver may pay to park at an off-street parking facility but miss the chance to obtain a nearby free on-street parking space that may better serve him. Third, from the city's point of view, parking space utilization becomes imbalanced: parking spaces for which information is provided are highly utilized and cause higher traffic congestion nearby, while other parking spaces may be routinely left vacant. In general, guidance systems do not solve the basic parking problem. Even worse, they may cause new traffic congestion in areas where parking spaces are monitored.

The Smart Parking (SP) system described here is based on a new concept which explicitly allocates and reserves optimal parking spaces to drivers, as opposed to simply guiding them to a space that may not be available by the time it is reached. The allocation is based on each user's objective function that combines proximity to destination and parking cost, while also ensuring that the overall parking capacity is efficiently utilized. Reservation in this system is different from those mentioned earlier, in that the latter only involve garage space reservations and there is no attempt at any form of optimality; in our SP system, drivers may reserve both off-street and on-street parking spaces which are selected to be optimal based on a well-defined objective function structure.

The Smart Parking System Framework

The proposed SP system adopts the basic structure of PGI systems as one of its components. In addition, it includes a Driver Request Processing Center (DRPC) and a Smart Parking Allocation Center (SPAC). A Parking Resource Management Center (PRMC) collects and updates all real-time parking information and disseminates it via VMS or Internet (basic functions of PGI systems). The DRPC gathers driver parking requests and real-time information (i.e. vehicle location), keeps track of driver allocation status, and sends back the assignment results to drivers. Based on the driver requests and parking resource states, the SPAC makes assignment decisions and allocates and reserves parking spaces for drivers. Further details on this framework can be found in (Geng & Cassandras, 2013).

The basic allocation process is described as follows. Drivers who are looking for parking spaces send requests to the DRPC. A request is accompanied by two requirements: a constraint (upper bound) on parking cost and a constraint (upper bound) on the walking distance between a parking spot and the driver's actual destination. It also contains the driver's basic information such as license number, current location, car size etc. The SPAC collects all driver requests in the DRPC over a certain time window and makes an overall allocation at decision points in time, seeking to optimize a combination of driver-specific and system-wide objectives. An assigned parking space is sent back to each driver via the DRPC. If a driver is satisfied with the assignment, he/she has the choice of whether to reserve that space. Once a reservation is made, the driver still has opportunities to obtain a better parking spot (with a guarantee that it can never be worse than the current one) before the current assigned spot is reached. The PRMC then updates the corresponding parking space from vacant to reserved, and provides the guarantee that other drivers have no permission to take that space. If a driver is not satisfied with the assignment (either because of limited resources or his own overly restrictive parking requirements) or if he/she fails to accept it for any other reason, he/she has to wait until the next decision point. During intervals between allocation decisions made by the center, drivers with no parking assignment have the opportunity to change their cost or walking-distance requirements, possibly to increase the chance of an allocation if the parking system is highly utilized (it is of course possible that no parking space is assigned to a driver).

The implementation of the SP system described above relies on four main requirements:

1. **Parking Space Detection.** The system relies on the availability of real-time parking information, based on which it makes and upgrades allocations for drivers. Moreover, whenever the system must make an allocation, it requires the location information of all vehicles with pending requests. Based on this information, it estimates the travelling time to an allocated spot and provides the driving directions to it. Current vehicle tracking devices/systems provide solutions to this problem. Vehicle tracking systems combine GPS tracking technology with flexible, advanced mapping and reporting software. A vehicle tracking device (possibly a smartphone) is installed on a vehicle which collects and transmits tracking data via a cellular or satellite network. The system receives real-time vehicle tracking updates, including location, direction, speed, idle time, start/stop and so on. This technology has already been widely used in bus systems.
2. **V2I and I2V Communication.** The second requirement involves effective two-way communication between vehicles and the allocation center (infrastructure): Vehicle-to-infrastructure (V2I) and Infrastructure-to-vehicle (I2V). In our system, V2I communication involves drivers sending their parking requests, providing driver information, and confirming reservation to the system. I2V communication includes the DRPC sending allocation results, driving directions, and payment details back to vehicles. A simple way to implement such communication is through mobile phones.

In our SP implementation, we have developed a smartphone application through which drivers interact with the system. Using the application, drivers may log into the system with a unique ID, associated with which are the driver's general information such as license number, credit card number, car size etc. The ID is registered by the driver, and the DRPC maintains a database to store basic driver information. In the application, drivers also have the option of choosing their destination, walking distance preference and parking cost tolerance. After the driver finishes all settings and sends out the request, the system will send back parking allocation results based on his parking preferences and the state of the system.

There are three kinds of allocation results: (*i*) If the system fails to find a parking space for the driver a notification asks the driver to wait for the next allocation time. A detailed explanation is also provided regarding the failed allocation; for example, there are no vacant parking spaces, the driver's requirements are too strict, or the driver is too far away from his destination. The driver may then either release his parking request by changing his preferences to increase the chance of an allocation, or simply do nothing and wait. (*ii*) If a parking space is allocated to the driver but he/she is not satisfied with it he/she can reject the allocation and adjust the requirements. However, by doing this he/she runs the risk of not being allocated a space at the next decision time. To prevent drivers from constantly rejecting successful allocations and adjusting requirements for better parking spots, or to prevent drivers from always providing extremely strict conditions at the beginning and gradually relaxing them later, the system may charge an increasing fee if the number of requests exceeds a certain threshold. (*iii*) If the driver is satisfied with the result, then the system reserves that space for him and the application shows the driving directions to the reserved parking space. While he/she is driving, the system may notify him about a better parking space based on his real-time position. The driver needs to respond and tell the system whether he/she accepts it or not. When the driver arrives at the parking spot, he/she needs to confirm that they are parking at the allocated spot.

Note that both V2I and I2V communication are implemented through a smartphone application, and data are transmitted through the cellular network. Drivers may reserve a parking space before a trip and interact with the system by simply pushing buttons on the smartphone, thus not distracting them from driving.

3. **Reservation Guarantee.** Parking reservations are a key feature of the SP system. In order to implement this function, when a parking space is reserved by the driver the system must guarantee that this will not be taken by other vehicles. For off-street parking resources, it is relatively easy to prevent drivers with no reservation from taking the space which has been reserved by someone else. The system can do ID checking (with RFID technology) at the gate of a garage or a parking lot. If the driver has made a reservation, then the gate opens and a space number is provided to him. If the driver did not make any reservation, then he/she may either be allowed to park if there are empty unreserved spaces, or prevented from entering.

For on-street parking resources, the reservation scheme is more complicated because there is no central ID checking location, meaning drivers may park at any space if it is vacant. One method is through wireless technology, interfacing a vehicle with hardware that makes a space accessible only to the driver who has reserved it. Examples include gates, "folding barriers," and obstacles that emerge from and retract to the ground under a parking spot; these are wirelessly activated by devices on board vehicles, similar to mechanisms for electronic toll systems. However, this method is relatively expensive, and the hardware is not easy to install or maintain. A "softer" scheme is to use a light system placed at each parking space, where different colors indicate different parking space states. In our system, we use a GREEN light to indicate that a vacant parking spot is available for any driver, a RED light to indicate that the spot is reserved by other drivers, a YELLOW (or blinking YELLOW for increased visibility) light to attract a driver in the vicinity who has reserved that space, and a blinking RED light to notify a driver who is parking at a space reserved by someone else. An LED light with these three colors is connected to and controlled by a sensor node placed at each parking space. When a driver is approaching the parking space reserved for him, this is automatically detected by the GPS data sent from his smartphone through our SP application (alternatively, the driver can explicitly notify the system). The system then sends a command to the sensor node which switches the light at his reserved space from RED to blinking YELLOW. The driver should then be able to recognize his reserved spot and park there. After parking, the light goes off until the car leaves and it returns to its GREEN state, or a RED state if the parking space is reserved. If a driver violates the rule and parks at a space reserved by someone else, the blinking RED provides a warning and the driver should leave. If he/she does not, the system knows which space is occupied and will penalize the driver (e.g. by issuing a ticket); in the meantime, the system makes a new assignment for the driver who had actually reserved that space. If the second assignment is worse than the previous one, then the driver receives compensation, which may come from the violator's fine.

4. **Optimal Allocation.** One of the benefits of the SP system is that it determines the best parking space for each driver. This is done through an efficient allocation algorithm executed at the SPAC. In what follows, we will limit ourselves to an outline of the methodology that enables us to make optimal parking space allocations and reservations, and point the reader to (Geng & Cassandras, 2013) for full technical details.

For the sake of generality, we will employ the term "user" when referring to drivers or vehicles, and the term "resource" when referring to parking spaces. We adopt a queueing model for the problem as shown in Figure 2, where there are N resources and every user arrives randomly to join an infinite-capacity queue (labeled WAIT) and waits to be assigned a resource if possible. At each decision point, the system makes allocations for all users in both the waiting queue and the queue of users (labeled RESERVE) who have already been assigned and have reserved a resource from a prior decision point. If a user in WAIT is successfully assigned a resource, he/she joins the RESERVE, otherwise he/she remains in WAIT. A user in RESERVE may be assigned a different resource after a decision point and remains in this queue until he/she can physically reach the resource and occupy it. A user leaves the system after occupying a resource for some amount of time, at which point the resource becomes free again.

At each decision point indexed by k, we define the state of the allocation system, $X(k)$, $k = 1,2,\ldots$, and the state of the ith user, $S_i(k)$, $i = 1,2,\ldots$, as explained next. First, we define

$$X(k) = \{W(k), R(k), P(k)\} \quad (1)$$

where $W(k) = \{i\text{: user } i \text{ is in the WAIT queue}\}$, $R(k) = \{i\text{: user } i \text{ is in the RESERVE queue}\}$, and $P(k)=\{p_1(k),..., p_N(k)\}$ is a set describing the state of the jth resource with $p_j(k)$ denoting the number of free parking spaces at resource j, $j=1,\ldots,N$ (this is possibly > 1 if a resource models a group of parking spaces, e.g. a parking garage, rather than an individual space.)

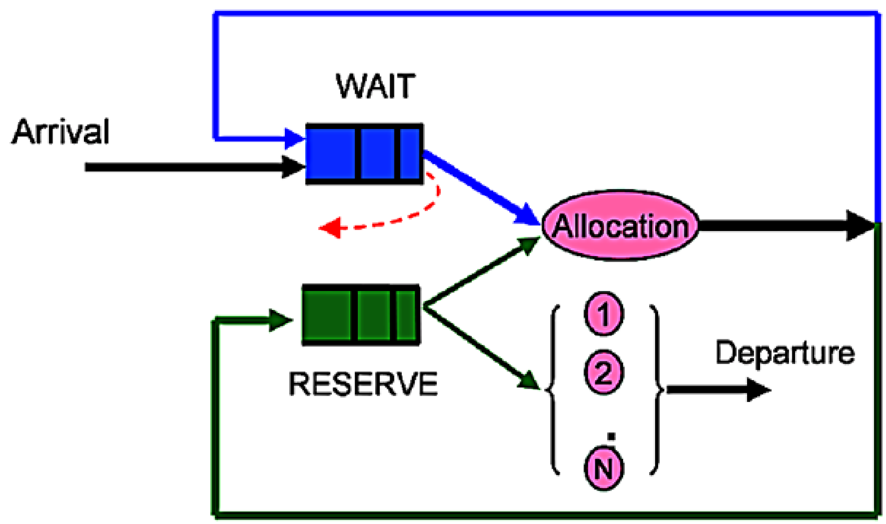
We assume that each resource has a known location associated to it, as denoted by $y_j \in Z \subset \mathbb{R}^2$. We also define

$$S_i(k) = \{z_i(k), r_i(k), q_i(k), \Omega_i(k)\} \quad (2)$$

where $z_i(k) \in Z \subset \mathbb{R}^2$ is the location of user, i, $r_i(k) \in \mathbb{R}^+$ is the total time that user i has spent in the RESERVE queue up to the kth decision point ($r_i(k) = 0$ if $I \in W(k)$), and $q_i(k)$ is the reservation status of user i:

$$q_i(k) = \begin{cases} 0 & \text{if } i \in W(k) \\ j & \text{if user } i \text{ has reseved resource } j \end{cases} \quad (3)$$

Figure 2. Queueing model for the Smart Parking system



Finally, $\Omega_i(k)$ is a feasible resource set for user i, i.e., $\Omega_i(k) \subseteq \{1,\ldots,N\}$ depending on the requirements set forth by this user regarding the resource requested. In general, $\Omega_i(k)$ may be a set specified by each user at each decision point; however, for the specific parking problem we are interested in, we will define $\Omega_i(k)$ in terms of attributes associated with user i, which are defined as follows. First, let D_i be an upper bound on the distance (walking distance or walking time) between the resource that the user is assigned and his actual destination $d_i \in Z \subset \mathbb{R}^2$. If the user is assigned a resource j located at y_j, let $D_{ij} = \|d_i - y_j\|$ where $\|\cdot\|$ is a suitable distance metric. Then, $D_{ij} < D_i$ defines a requirement imposed by user i.

The second attribute for user i, denoted by M_i, is an upper bound on the cost this user is willing to tolerate for the benefit of reserving and subsequently using a resource. The actual cost depends on the specific pricing scheme adopted by the allocation system, which our approach does not depend on. We only assume that each user cost is a monotonically non-decreasing function of the total reservation time $r_i(k)$, user expected occupancy time c_i and a function of the traveling time from the user location at the kth decision time, $z_i(k)$, to a resource location y_j. Let $s_{ij}(k) = \|z_i(k) - y_j\|$ be this distance, and define the traveling time $t_{ij}(k) = f(s_{ij}(k), \omega)$ where ω is a random vector capturing all stochastic traffic conditions. We use $M_{ij}(r_i(k), t_{ij}(k), c_i)$ to denote the total expected monetary cost for using resource j, evaluated at the kth decision time. Once a pricing scheme is known, $M_{ij}(r_i(k), t_{ij}(k), c_i$ can be evaluated if all random variables involved are characterized by known probability distributions. Alternatively, an estimate of $M_{ij}(r_i(k), t_{ij}(k), c_i$ can be computed. Comparing $M_{ij}(r_i(k), t_{ij}(k), c_i$ to M_i, leads to the constraint $M_{ij}(r_i(k), t_{ij}(k), c_i) \leq M_i$.

In order to fully specify $\Omega_i(k)$, we further define $\Gamma(k) = \{j: p_j(k) > 0, j = 1,\ldots,N\}$ to be the set of free and reserved resources at the kth decision time and set

$$\Omega_i(k) = \{j: M_{ij}(k) \leq M_i, D_{ij} \leq D_i, j \in \Gamma(k)\} \quad (4)$$

where, for simplicity, we have written $M_{ij}(k)$ instead of $M_{ij}(r_i(k), t_{ij}(k), c_i)$. Note that this set allows the system to allocate to user i any resource $j \in \Omega_i(k)$ which satisfies the user's requirements even if it is currently reserved by another user. Thus, a resource j may be dynamically re-allocated to different users at each decision point until $p_{ij}(k) = 0$, signaling that there is no available resource.

Using the definitions of D_{ij}, D_i, M_{ij}, and M_i, we specify an objective function $J_{ij}(k)$ which we will seek to minimize at each decision point by allocating resources j to user i:

$$J_{ij}(k) = \lambda_i \frac{M_{ij}(k)}{M_i} + (1-\lambda_i)\frac{D_{ij}}{D_i} \tag{5}$$

where $\lambda_i \in [0,1]$ is a weight that reflects the relative importance assigned by the user between cost and resource quality, measured as the walking distance between the parking spot the user is assigned and his actual destination. In a SP system, the objective is to make allocations for as many users as possible and, at the same time, to achieve minimum user cost, as measured by $J_{ij}(k)$. We introduce binary control variables

$$x_{ij} = \begin{cases} 1 & \text{if user } i \text{ is assigned to resource } j \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

and define the matrix $X = [x_{ij}]$. We can now formulate the SP optimal allocation problem at the kth decision point as follows:

$$\min_X \sum_{i\in W(k)\cup R(k)} \sum_{j\in\Omega_i(k)} x_{ij} \cdot J_{ij}(k) + \sum_{i\in W(k)} \left(1 - \sum_{j\in\Omega_i(k)} x_{ij}\right)$$
$$s.t. \tag{7}$$

$$\sum_{j\in\Omega_i(k)} x_{ij} \le 1, \quad \forall_i \in W(k) \tag{8}$$

$$\sum_{j\in\Omega_i(k)} x_{ij} = 1, \quad \forall_i \in R(k) \tag{9}$$

$$\sum_{i\in W(k)\cup R(k)} x_{ij} \le p_j(k), \quad \forall_j \in \Gamma(k) \tag{10}$$

$$\sum_{j\in\Omega_i(k)} x_{ij} \cdot J_{ij}(k) \le J_{iq_i(k-1)}(k), \quad \forall i \in R(k) \tag{11}$$

$$x_{ij} \in \{0,1\}, \quad \forall_i \in W(k) \cup R(k), \quad j \in \Gamma(k) \tag{12}$$

$$\left[\sum_{n\in\Omega_i(k)} x_{in}\right] - x_{mj} \ge 0,\ \forall i,j,m \ \ s.t.\ j \in \Gamma(k), j \in \Omega_i(k), \tag{13}$$

$$m \in W(k), t_{mj} > t_{ij} \tag{14}$$

Complete details on this problem formulation are given in (Geng & Cassandras, 2013). We limit ourselves here to pointing out that the term

$$\min \textstyle\sum_{i\in W(k)\cup R(k)} \sum_{j\in\Omega_i(k)} x_{ij} \cdot J_{ij}(k)$$

in (7) aims to find the minimum cost over all users. If the system fails to allocate a resource to some users i, i.e.

$$\textstyle\sum_{j\in\Omega_i(k)} x_{ij} = 0,$$

a cost of 1 is added to the objective function. Therefore, the added term

$$\textstyle\sum_{i\in W(k)} (1 - \sum_{j\in\Omega_i(k)} x_{ij})$$

in (7) is the total cost contributed by the number of "unsatisfied" users. The constraints (8) indicate that any user in the WAIT queue may be assigned at most one resource but may also fail to get an assignment. On the other hand, (9) guarantees that each user in the RESERVE queue maintains a resource assignment. The capacity constraints (10) ensure that every resource is occupied by no more than $p_j(k)$ users. The constraints (11) add a unique feature to our problem by guaranteeing that every user in the RESERVE queue is assigned a resource which is no worse than the one most recently reserved, i.e. $q_i(k\text{-}1)$. Together, (9) and (11) ensure a reservation guarantee and improvement. Finally, (13) is a set of fairness constraints to ensure that a waiting user located right next to an available resource is not assigned to another waiting user at a considerably larger distance from it (a detailed explanation of these constraints is given in (Geng & Cassandras, 2013).

Note that in-between any two decision points, users in the waiting queue who are close to their destination may reach it before having an opportunity to be assigned a parking space. To deal with this effect, we adopt the following Immediate Allocation (IA) policy: Whenever user i is in the WAIT queue and reaches a location z_i such that $\|z_i - d_i\| \le v_i\tau$, he/she is placed in an "immediate allocation" queue. Here, τ is the decision interval and v_i is the average driving speed. If this queue is not empty, as soon as a user departure makes a resource available the system immediately prioritizes user i over other users in $W(k)$ and assigns him this resource if it is feasible. This "immediate allocation" problem is easy to solve. We define an "urgent" user set

$$I(k) = \{i: i \in W(k), \|z_i - d_i\| \le v_i\tau\}$$

and, as soon as a resource j becomes free, we allocate it to user i such that $J_{ij} = \min_{n\in I(k),\ j\in\Omega n(k)} J_{nj}$, if such i exists.

The problem (7) is a mixed integer linear program (MILP) known to be NP-hard and its solution is obtained using any of several commercial software packages available. There are various simple means through which the computational complexity of such problems can be managed, which are discussed in (Geng & Cassandras, 2013). We will briefly mention two of them: (*i*) Area partitioning: this entails partitioning an area into several small "districts." For each district, problem (7) is solved for all drivers whose destinations are located in the district, noting that drivers whose destinations are on the border of two adjacent districts are considered for allocation in both districts. (*ii*) Grouping resources: even in a single district the total number of parking spaces may be large; however, drivers normally do not request a specific spot, but only care for a street or garage to park. Therefore, all spaces in the same garage or parking lot can be treated as a single resource. Similarly, we can group all on-street parking spots in the same street block as one resource. The system may then randomly pick a vacant spot for the driver when he/she arrives, allowing for a drastic reduction in the problem size.

Next, we present a number of performance metrics allowing us to assess the overall system performance over a time interval $[0,T]$ with a total number of users N_T served over this interval (e.g. a simulation run length).

From the system's point of view, we consider resource utilization as a performance metric and break it down into two parts: $u_r(T)$ is the utilization of resources by reservation (i.e. the fraction of resources that are reserved) and $u_p(T)$ is the utilization by occupancy (i.e. the fraction of resources that are physically occupied by a user).

From the user's point of view, we use (5) for those users that actually occupy a resource. Let $P(T)$ be the set of such users over $[0,T]$. Moreover, let $q_i^* \in \{1,...,N\}$ be the resource ultimately assigned to user $i \in P(T)$. We then define

$$J_{iq_i^*} = \lambda_i \frac{M_{iq_i^*}}{M_i} + \left(1-\lambda_i\right)\frac{D_{iq_i^*}}{D_i}$$

and

$$\bar{J}(T) = \frac{1}{|P(T)|} \sum_{i \in P(T)} J_{iq_i^*}$$

measuring the average cost of users served. In addition, unlike traditional queuing problems, waiting times are not a measure of user satisfaction, since users do not actually need a resource until they have physically reached it. Instead, another metric we will use is the wandering ratio $w(T)$, defined as follows. Let

$$A_W(k) = \{i: i \in W(k), \|z_i(k) - d_i\| \le \varepsilon\}$$

be the set of users who reach their destination but are still in the WAIT queue at the kth decision point, where ε is a small real number used to indicate that a user is in the immediate vicinity of his destination d_i. Letting k_T denote the last decision point within the time interval of length T, we then define

$$w(T) = \frac{A_W(k_T)}{N_T} \tag{15}$$

Finally, we consider the average time-to-park $t_p(T)$, which is the time from the instant a user sends a parking request to the instant he/she physically occupies a parking resource.

Case Study and Pilot Implementation

A simulation case study of the SP system was performed for part of the Boston University main campus within the city of Boston, an area that includes 679 on-street parking spaces and 1932 off-street parking spaces. We assumed that all these spaces were monitored and could be used by any driver (student, faculty or visitor) without any time limit. To reduce computational complexity, we adopted a "resource grouping" method by aggregating the 679 on-street parking spaces into 27 groups and the 1932 off-street parking spaces into 14 groups. Following the same strategy, we also aggregated driver destinations: buildings in the same block are treated as a single destination and we considered a total of 12 destinations. Detailed results of this case study may be found in (Geng & Cassandras, 2013). We will limit ourselves to a summary of the main findings which are as follows:

- Parking space utilization under the SP system increased by 10-20% relative to uncontrolled or guidance-based parking scenarios. This implies higher revenues for the city and parking facility operators, as well as lower traffic congestion.
- The fraction of unsatisfied drivers (i.e. those who are never assigned a parking space), as measured by the abandon cost metric (14), was virtually eliminated with the SP system under normal traffic conditions and was found to be less than 2% under high traffic conditions. In contrast, this fraction is about 20% when using guidance-based systems and 60% in uncontrolled scenarios. Once again, this implies higher revenues for the city and parking facility operators, as well as lower traffic congestion.
- The average time-to-park under the SP system was reduced by about 30% in normal traffic and 50% in heavy traffic conditions. This implies significantly less congestion along with reduced fuel waste and associated pollution.

A pilot implementation of the SP system was carried out at a Boston University parking facility which contains 27 parking spaces (details may be found in (Geng & Cassandras, 2013)). At each parking space, a Streetline (Streetline, 2012) parking detection sensor was installed on the ground, as well as an LED device for controlling our light system, as described earlier. A Streetline gateway receives data from each sensor in the network and forwards it to an upper level database which serves as the PRMC with the state (vacant or occupied) of each parking space. The real-time parking information is published and updated on the web and can be obtained by users. Thus, our system still provides the service of a normal PGI system. We have also installed cameras and used standard image processing algorithms based on which the state of each parking space (vacant or occupied) is determined; the joint data from the ground sensors and the cameras are combined to increase the reliability of parking state estimates.

We have also built a smartphone application (see http://smartpark.bu.edu/smartparking/home.php*?*) through which users can send parking requests and obtain reservations. The application sends all user requests to a computer which serves as both DRPC and SPAC in our SP system framework. The computer maintains all driver requests, solves the optimal allocation problem (7), updates the parking space state database, and sends commands to control the state of the light at each parking space device. Figure 3 shows the smartphone application and real-time parking information website.

Dynamic Allocation and Space Reservation for Electric Vehicles at Charging Stations

Electric Vehicles (EVs) offer a promising, cleaner alternative to conventional fossil-fueled vehicles in urban environments. Their proliferation, however, comes at the cost of dealing with their limited cruising range, long charge times, and a sparse coverage of charging stations for the foreseeable future. Focusing on the problem of recharging, the sparseness of charging stations makes it critical for an EV to identify an optimal station given its current location, destination, and charge state. Moreover, the limited capacity of charging spaces at a station creates an additional difficulty

Figure 3. Smart parking iPhone application and website

similar to the classic parking problem discussed in the previous section. In fact, the main principles used for the SP system we have presented can be extended and specifically designed so as to optimally allocate and reserve charging spaces for EVs, as opposed to simply guiding them to a space that may not be available by the time it is reached. As in the SP system, the allocation is based on the user's objective function, which combines proximity to the EV's current location (or its ultimate destination) and the charging cost, while also ensuring that the overall charging space capacity is efficiently utilized with a built-in fairness guarantee.

As in the case of SP, the physical realization of a system for allocating EVs to charging station spaces requires (*i*) detecting spaces at charging stations, (*ii*) effective wireless communication between EVs and a server where spaces are allocated, (*iii*) guaranteeing space reservations through a light system identical to the one used in SP, and (iv) optimal allocation carried out through an efficient allocation algorithm similar to (7) used in the SP system. We omit further details, which may be found in (Cassandras & Geng, 2014).

A simulation case study reported in (Cassandras & Geng, 2014) indicates that improvements similar to those observed for the SP system can be achieved. For a typical scenario, charging space utilization was found to increase by 14% compared to a guidance-based system, the time to a charging space was reduced by 9.5%, and the wandering ratio was reduced by 30%.

Adaptive Traffic Light Control

We now turn our attention to the problem of traffic flow control in urban environments. As mentioned earlier, there are a relatively small number of controls at our disposal when it comes to traffic regulation. Traffic Light Control (TLC) is the main mechanism to accomplish this goal. The TLC problem consists of adjusting green and red light cycles in order to control the traffic flow through an intersection and, more generally, through a set of intersections and traffic lights in an urban roadway network. The ultimate objective is to minimize congestion (hence delays experienced by drivers and resulting reductions in fuel usage and pollution) at a particular intersection, as well as an entire area consisting of multiple intersections. There are two types of control strategies for the TLC problem in the literature: fixed-cycle and traffic-responsive strategies. In the former, several timing plans covering different traffic-intensity scenarios are periodically interchanged; for example, the Urban Traffic Control System (UTCS) (Wey, 2000), TRANSYT (Robertson, 1969), and MAXBAND (Little et al., 1981) all make use of historical traffic flow data to determine light cycles offline and cannot adapt in real time to evolving traffic conditions. Traffic-responsive strategies address this limitation by making use of current traffic information to determine optimal signal settings online. They employ algorithms that adjust a signal's phase length and phase sequences so as to minimize delays and reduce the number of stops, requiring transit surveillance, typically implemented using pavement loop detectors, in order to adjust signal timing in real time. The two most widely used systems of this type are SCATS (Lowrie, 1982) and SCOOT (Hunt et al., 1982).

In a Smart City setting, one can exploit technological developments for collecting traffic data in real time and making it possible for new methods to be applied to the TLC problem, e.g. systems such as ACS Lite (Shelby et al., 2008), OPAC (Gartner et al., 2002), PRODYN (Henry & Farges, 1990), and RHODES (Sen & Head, 1997). Leveraging the fact that TLC is fundamentally a form of scheduling for systems operating through simple switching control actions, numerous solution algorithms have been proposed, including fuzzy logic methods (Pappis & Mandani, 1977; Choi et al., 2002), expert systems (Findler & Strapp, 1992; Findler et al., 1997; Wen & Hsu, 2006), evolutionary algorithms (Liu, 2007), swarm optimization (Dong, 2004; Dong, 2006), ant algorithms (Wen & Wu, 2005), and artificial neural networks (Dong et al., 2005; Henry et al., 1998; Spall & Chin, 1997). Reinforcement learning has also been used (as reported in (Abdulhai et al., 2003; Bazzan, 2009; Prashant & Bhatnagar, 2011; Wiering et al., 2004) and a game theoretic approach was applied to a finite controlled Markov chain model in (Alvarez & Poznyak, 2010). In (Porche et al., 1996,) a decision tree model was used with a Rolling Horizon Dynamic Programming (RHDP) approach, while a multiobjective Mixed Integer Linear Programming (MILP) formulation was proposed in (Dujardin et al., 2011). Optimal TLC was also stated as a special case of an Extended Linear Complementarity Problem (ELCP) in (DeSchutter, 1999), and formulated as a hybrid system optimization problem in (Zhao & Chen, 2003).

The aforementioned methods for real-time adaptive traffic control must address two main issues: the development of a mathematical model for a stochastic and highly nonlinear traffic system, and the design of appropriate control laws. Although most existing adaptive signal control strategies implicitly recognize that variations in traffic conditions are caused by random processes, they frequently resort to using deterministic models, which significantly simplify the description of vehicle flow. In addition to this, heuristic control strategies are also commonly employed for TLC without an embedded traffic flow model, as in the case of artificial intelligence techniques, which rely on historical data. Such applications are, as a result, better suited for traffic systems in steady state, which is in fact seldom attained. Stochastic control approaches address this limitation by explicitly accounting for the random variations in traffic flow, typically within a Markov Decision Process (MDP) framework, which requires specific probabilistic models. Furthermore, many of these approaches, such as those based on dynamic programming, are computationally inefficient, thus not immediately amenable to online implementations. In contrast to the above, perturbation analysis techniques (Cassandras & Lafortune, 2008) allow for stochastic control without the need to assume any particular probabilistic traffic models and have proven to be adaptive and easily implementable online.

Perturbation analysis was used in (Fu & Howell, 2003; Head et al., 1996) based on modeling a traffic light intersection as a stochastic Discrete Event System (DES). An Infinitesimal Perturbation Analysis (IPA) approach, using a Stochastic Flow Model (SFM) to represent the queue content dynamics of roads at an intersection, was presented in (Panayiotou et al., 2005). IPA was also applied with respect to controllable green and red cycle lengths for a single isolated intersection in (Geng & Cassandras; 2012b), and for multiple intersections in (Geng & Cassandras, 2012a; Geng & Cassandras, 2014). Modeling traffic flow through an intersection controlled by switching traffic lights as an SFM conveniently captures the system's inherent hybrid nature: while traffic light switches exhibit event-driven dynamics, the flow of vehicles through an intersection is best represented using time-driven dynamics. Moreover, traffic flow rates need not be restricted to take on deterministic values, but may be treated as stochastic processes (Cassandras et al., 2002) which are suited to representing the continuous, random variations in traffic conditions. Using the general IPA theory for Stochastic Hybrid Systems (SHS) in (Cassandras et al., 2010; Wardi et al., 2010), online gradients of performance measures may be estimated with respect to several controllable parameters with only minor technical conditions imposed on the random processes that define input and output flows at an intersection. More recently, a quasi-dynamic control setting was proposed in (Fleck & Cassandras, 2014), in which partial state information is used to adjust the light cycle lengths conditioned upon a given queue content threshold being reached. This sets the stage for what is becoming a growing trend towards exploiting connected vehicle technology to infer vehicle state information from data (e.g.

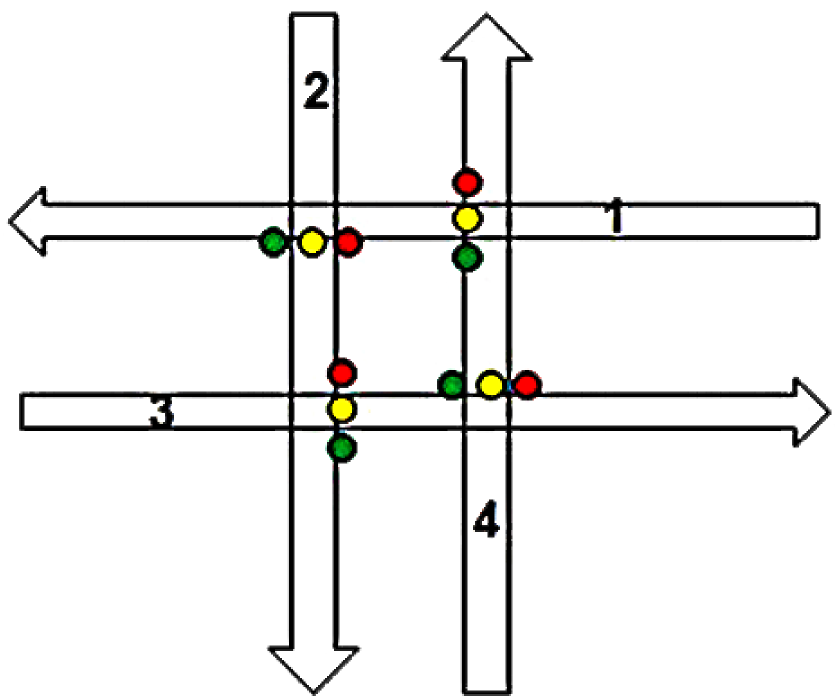
location, speed) wirelessly exchanged through vehicle-to-vehicle or vehicle-to-infrastructure communication (Dressler et al., 2014). This activity points the way towards so-called Virtual Traffic Lights (VTL) for eventually eliminating actual traffic lights. The idea is to equip vehicles with a display that emulates a traffic light, indicating to individual drivers whether they can proceed through an intersection without stopping (green light) or not (subject, of course, to pedestrian traffic constraints).

In the remainder of this section, we limit ourselves to the simplest single-intersection model studied to date as a stochastic hybrid system (Geng & Cassandras; 2012b), based on which IPA techniques have been used to derive a gradient estimator of a congestion metric and, subsequently, combined with a gradient-based algorithm to adaptively adjust the RED/GREEN cycle times seeking to optimize this metric.

Traffic Light Control Problem Formulation

We consider a single isolated intersection, as shown in Figure 4. There are four roads and four traffic lights, with each traffic light controlling the associated incoming traffic flow. For simplicity, we make the following assumptions: (i) Left-turn and right-turn traffic flows are not considered, i.e. traffic lights only control vehicles going straight. (ii) Traffic lights for any two roads with opposite directions are synchronized: if the traffic light for road 1(2) is GREEN, the light for road 3(4) is also

Figure 4. A single intersection



GREEN and the lights for roads 2 and 4 (1 and 3) are RED. (iii) A YELLOW light is combined with a RED light (therefore, the YELLOW light duration is not explicitly controlled).

Viewed as a dynamic system, the operation of the intersection involves a number of stochastic processes. Each of the four roads is considered as a queue with a random arrival flow process

$\{\alpha_n(t)\}$, $n = 1,\ldots,4$,

where $\alpha_n(t)$ is the instantaneous vehicle arrival rate at time t. When the traffic light corresponding to road n is GREEN, the departure flow process is denoted by $\{\beta_n(t)$, $n = 1,\ldots,4$. Let the GREEN light duration in a cycle of queue n be

$\theta_n \in [\theta_{n\min}, \theta_{n\max}] \subset \mathbb{R}^+$ with $\theta_{n\min} > 0$.

By the second assumption above, we have $\theta_1 = \theta_3$ and $\theta_2 = \theta_4$ so that the controllable parameter vector of interest is $\theta = [\theta_1, \theta_2]$. We define a state vector

$x(\theta,t)=[x_1(\theta,t), x_2(\theta,t), x_3(\theta,t), x_4(\theta,t)]$

where $x_n(\theta,t) \in \mathbb{R}^+$ is the content of queue n. We use the notation $x_n(\theta,t)$ to emphasize the dependence of the queue content on θ; however, for notational simplicity, we will write $x_n(t)$ when no confusion arises. We also define a "clock" state variable $z_i(t)$, $I = 1,2$, associated with the GREEN light cycle for queues {1,3} and {2,4} respectively as follows:

$$\dot{z}_i(t) = \begin{cases} 1 & if\, 0 < z_i(t) < \theta_i \ or \ z_j(t) = \theta_j, j \neq i \\ 0 & otherwise \end{cases}$$
$$z_i(t^+) = 0 \ if \ z_i(i) = \theta_i \tag{16}$$

and set $z(t)=[z_1(t), z_2(t)]$ with any initial states such that $z_1(0)\cdot z_2(0) > 0$. Thus, $z_1(t)$ measures the time since the last switch from RED to GREEN of the traffic light for queues {1,3}. It is reset to 0 as soon as the GREEN cycle length θ_1 is reached and remains at this value while the light is GREEN for queues {2,4}. As soon as that cycle ends, i.e. $z_2(t) = \theta_2$, then $z_1(t) = 1$ and the process repeats. The same applies to $z_2(t)$ measuring the time since the last switch from RED to GREEN of the traffic light for queues {2,4}.

We can now write the dynamics of each state variable $x_n(t)$ as follows:

$$x_n(t) = \begin{cases} \alpha_n(t) \quad if \ z_1(t) = 0, n = 1,3 \ or \ z_2(t) = 0, n = 2,4 \\ 0 \quad if \ x_n(t) = 0 \ and \ \alpha_n(t) < \beta_n(t) \\ \alpha_n(t) - \beta_n(t) \quad otherwise \end{cases} \tag{17}$$

The operation of the intersection can be viewed as a hybrid system with the time-driven dynamics described by (15)-(16) and event-driven dynamics dictated by GREEN-RED light switches and by events causing some $x_n(t)$ to switch from positive to zero or vice versa. Using the standard definition of a Stochastic Hybrid Automaton (SHA) (e.g. see Cassandras et al., 2010), we have a SHA for the operation of each queue as shown in Fig. 5, where we take queue $n = 1$ for example without loss of generality. This reflects the fact that a typical sample path of any one of the queue contents consists of intervals over which $x_n(t) > 0$, which we call Non-Empty Periods (NEPs), followed by intervals where $x_n(t) = 0$, which we call Empty Periods (EPs). Thus, the entire sample path consists of a series of alternating NEPs and EPs. The event set that affects any such queue is $E = \{e_1, e_2, e_3, e_4, e_5\}$ where e_1 is a switch in the sign of $\alpha_n(t)$ - $\beta_n(t)$ from non-positive to strictly positive, e_2 is a switch in the sign of $\alpha_n(t)$ from 0 to strictly positive, e_3 is the queue content becoming empty, i.e. $x_n = 0$, which terminates a NEP (and initiates an EP), e_4 switches a light from RED to GREEN, and e_5 switches a light from GREEN to RED. For easier reference, we label e_3 as "E" for the end of NEP events, e_4 as "R2G" and e_5 as "G2R" for the light switching events. Observe that the start of a

NEP may occur through a transition from mode 3 to either 1 or 2 in Fig. 5. This can happen in three ways: (*i*) When a G2R event occurs in mode 3 provided $\alpha_1(t) > 0$, (*ii*) When a switch of $\alpha_1(t)$ from zero to a strictly positive value occurs during a RED cycle (i.e. $z_1(t) = 0$) in mode 3, and (*iii*) When a switch of $\alpha_1(t) - \beta_1(t)$ from a non-positive to a strictly positive value occurs during a GREEN cycle (i.e. $z_1(t) > 0$) in mode 3. Thus, the resulting start of a NEP is an event "induced" by either e_5 or e_2 or e_1, which we will refer to as an "S" event.

The *m*th NEP in a sample path of any queue, $m = 1,2,\ldots$, is denoted by $[\xi_{n,m}, \eta_{n,m})$, i.e. $\xi_{n,m}$, $\eta_{n,m}$ are the occurrence times of the *m*th S and E event respectively at this queue. During the *m*th NEP, $t_{n,m}^{j}$, $j = 1,\ldots, J_m$ denotes the time when a traffic light switching event occurs (either R2G or G2R). Our objective is to select θ so as to minimize a cost function that measures a weighted mean of the queue lengths over a fixed time interval $[0,T]$.

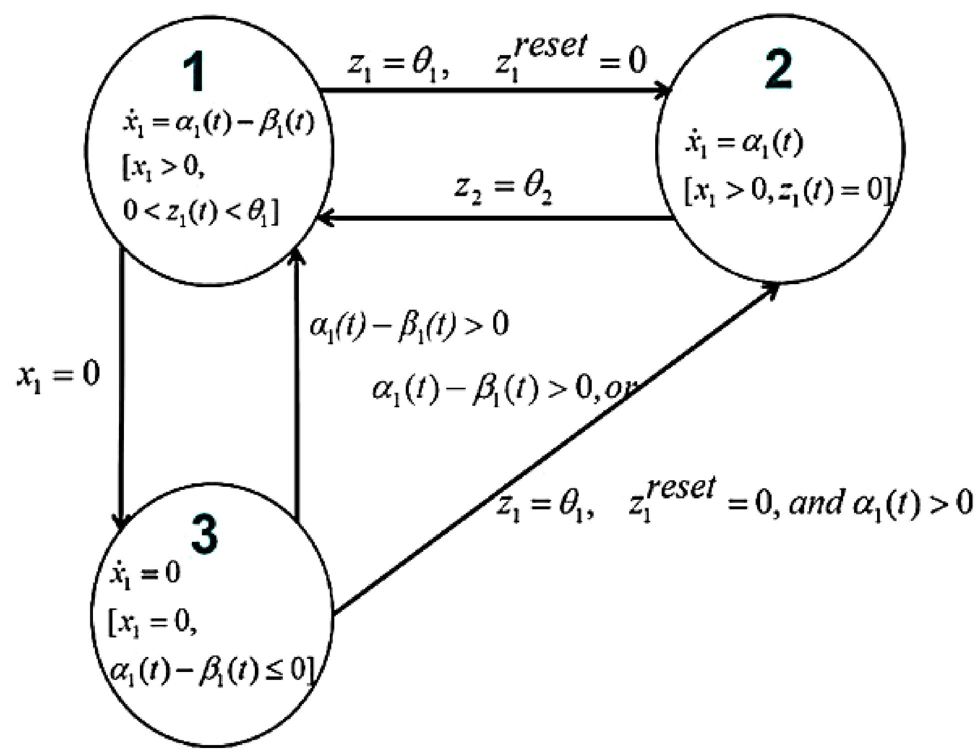
In particular, we define

$$L\left(\theta; x\left(0\right), z\left(0\right), T\right) = \frac{1}{T}\sum_{n=1}^{4}\int_{0}^{T} w_n x_n \left(\theta, t\right) dt \tag{18}$$

where w_n is a cost weight associated with queue n and $x(0)$, $z(0)$ are given initial conditions. It is obvious that since $x_n(t) = 0$ during EPs of queue n, we can rewrite (18) as:

$$L\left(\theta; x\left(0\right), z\left(0\right), T\right) = \frac{1}{T}\sum_{n=1}^{4}\sum_{m=1}^{M_n}\int_{\xi_{n,m}}^{\eta_{n,m}} w_n x_n \left(\theta, t\right) dt \tag{19}$$

Figure 5. Stochastic hybrid automaton for one of the roads in a single intersection



here M_n is the total number of NEPs during the sample path of queue n. For convenience, we also define

$$L_{n,m}(\theta) = \int_{\xi_{n,m}}^{\eta_{n,m}} w_n x_n(\theta, t)\, dt \tag{20}$$

to be the sample cost associated with the mth NEP of queue n. We can now define our overall performance metric as

$$J(\theta; x(0), z(0), T) = E\left[L(\theta; x(0), z(0), T)\right] \tag{21}$$

Since we do not impose any limitations on the processes $\{\alpha_n(t)\}$, $\{\beta_n(t)\}$, it is infeasible to obtain a closed-form expression of $J(\theta; x(0), z(0), T)$. The only assumption we make is that $\alpha_n(t)$, $\beta_n(t)$ are piecewise continuous w.p. 1. The value of IPA as developed for general stochastic hybrid systems in (Cassandras et al., 2010) is in providing the means to estimate the performance metric gradient $\nabla J(\theta)$ by evaluating the sample gradient $\nabla L(\theta)$. As shown in (Cassandras et al., 2010), these estimates are unbiased under mild technical conditions. Moreover, an important property of IPA estimates is that they are often independent of the unknown processes $\{\alpha_n(t)\}$ and $\{\beta_n(t)\}$ or they depend on values of $\{\alpha_n(t)\}$ or $\{\beta_n(t)\}$ at specific event times only. Such robustness properties of IPA make it attractive for estimating online performance sensitivities with respect to controllable parameters such as θ in our case. One can then use this information to either improve performance or, under appropriate conditions, solve an optimization problem and determine an optimal θ^* through an iterative scheme:

$$\theta_{i,k+1} = \theta_{i,k} - \gamma_k H_{i,k}(\theta_k, x(0), T, \omega_k),\ k = 0,1,... \tag{22}$$

where $H_{i,k}(\theta_k, x(0), T, \omega_k)$ is an estimate of $dJ/d\theta_i$ based on the information obtained from the sample path denoted by ω_k, and γ_k is the step size at the kth iteration. Next we will focus on how to obtain $dL/d\theta_i$, $i = 1,2$. We may then also obtain θ^* through (22) provided that $\{\alpha_n(t)\}$ and $\{\beta_n(t)\}$ are stationary. We will assume that the derivatives $dL/d\theta_i$, $i = 1,2$ exist for all $\theta_i \in \mathbb{R}^+$ w.p. 1.

Infinitesimal Perturbation Analysis (IPA)

Consider a sample path of the system as modeled in Fig. 5 over $[0,T]$ and let $\tau_k(\theta)$ denote the occurrence time of the kth event (of any type), where we stress its dependence on θ. To simplify notation, we define the derivatives of the states $x_n(t, \theta)$ and $z_i(t, \theta)$ and event times $\tau_k(\theta)$ with respect to θ_i, $i = 1,2$ as follows:

$$x'_{n,i}(t) \equiv \frac{\partial x_n(\theta,t)}{\partial\theta_i},\ z'_{i,i}(t,\theta) \equiv \frac{\partial z_i(\theta,t)}{\partial\theta_i},\ \tau'_{k,i} \equiv \frac{\partial\tau_k(\theta)}{\partial\theta_i} \tag{23}$$

Taking derivatives with respect to θ_i in (19), and observing that $x_n(\xi_{n,m}) = x_n(\eta_{n,m}) = 0$, we obtain

$$\frac{dL(\theta)}{d\theta_i} = \frac{1}{T}\sum_{n=1}^{4}\sum_{m=1}^{M_n} w_n \frac{dL_{n,m}(\theta)}{d\theta_i} \tag{24}$$

In view of (19), observe that the determination of the sample derivatives depends on the state derivatives $x'_{n,i}(t,\theta)$. The purpose of IPA is to evaluate these derivatives as functions of observable sample path quantities. In what follows, we omit technical details (which can be found in Geng & Cassandras, 2012b) and provide the event time derivatives and state derivatives derived by using IPA after each of the four event types (E, S, R2G, G2R) for queue n as defined in the previous section.

1. *Event* E *ending a* NEP *at time* $\eta_{n,m}$:

$$x'_{n,i}(\eta^{+}_{n,m}) = 0 \tag{25}$$

indicating that these state derivatives are always reset to 0 upon ending a NEP.

2. *Event* G2R, *i.e. a* GREEN *light switching to* RED: Letting $\zeta_{n,k}$ be the total number of G2R events that have occurred at queue *n* before or at time τ_k, it can be shown that

$$\tau'_{k,i} = \zeta_{n,k} \tag{26}$$

where $i = 1$ if $n \in \{1,3\}$ and $i = 2$ if $n \in \{2,4\}$. We can then obtain:

$$x'_{n,i}(\tau^{+}_{k}) = x'_{n,i}(\tau^{-}_{k}) - \begin{cases} \beta_n(\tau_k)\cdot\zeta_{n,k} & if\ x_n(\tau_k) > 0 \\ \alpha_n(\tau_k)\cdot\zeta_{n,k} & if\ x_n(\tau_k) = 0 \end{cases} \tag{27}$$

3. *Event* R2G, *i.e. a* RED *light switching to* GREEN:

$$x'_{n,i}(\tau^{+}_{k}) = x'_{n,i}(\tau^{-}_{k}) + \beta_n(\tau_k)\cdot\zeta_{n,k} \tag{28}$$

4. *Event* S *starting a* NEP: This is an event induced by e_5, or e_2, or e_1. Consequently, there are three possible cases to consider as follows.

   Case (4a): *A* NEP *starts right after a* G2R *event*:

$$x'_{n,i}(\tau^{+}_{k}) = -\alpha_n(\tau_k)\cdot\zeta_{n,k} \tag{29}$$

   Case (4b): *A* NEP *starts while* z_1=0, z_2>0 (without loss of generality, we assume $n\in\{1,3\}$): $\tau'_{k,i} = 0$ and $x'_{n,i}\left(\tau^{+}_{\boldsymbol{k}}\right) = 0$.

   Case (4c): *A* NEP *starts while* z_2=0, z_1>0 (without loss of generality, we assume $n\in\{1,3\}$): $\tau'_{\boldsymbol{k},\boldsymbol{i}} = 0$ and $x'_{n,i}\left(\tau^{+}_{\boldsymbol{k}}\right) = 0$.

This completes the derivation of all state and event time derivatives required to evaluate the sample performance derivative in (23). Using the definition of $L_{n,m}(\theta)$ in (19), note that we can decompose (23) for each $n = 1,\ldots,4$ into its NEPs and evaluate the derivatives $dL(\theta)/d\theta_i$.

What is important to point out is that despite the elaborate notation involved in the derivation of IPA estimators, their actual implementation is very simple. In fact, the IPA estimator requires only knowledge of: (*i*) the event times $\xi_{n,m}$, $\eta_{n,m}$, and $t^{j}_{n,m}$, $j = 1,\ldots, J_m$ and (*ii*) the value of the state derivatives at event times $t = \xi_{n,m}$, $t = t^{\boldsymbol{J_{n,m}}}_{n,m}$ and $t = t^{\boldsymbol{j}}_{n,m}$. The quantities in (*i*) are easily observed using timers whose start and end times are observable events. The state derivatives in (ii) are obtained from the expressions derived at event occurrence times (24)-(28) above, noting that $x'_{n,i}\left(\eta^{+}_{n,m}\right) = 0$ at the end of every NEP. Ultimately, these expressions depend on the values of the arrival and departure rates $\alpha_n(t)$ and $\beta_n(t)$ at light switching event times *only*, which may be estimated through simple rate estimators. As a result, it is straightforward to implement an algorithm for updating the value of $dL_{n,m}(\theta)/d\theta_i$ after each observed event.

We also point out that the IPA estimator is linear in the number of observed events, not in the states. This is a crucial observation because it implies that our approach scales with the number of traffic lights in a network of interconnected intersections, so that extensions from a single intersection to many interconnected intersections can be carried out with no excessive additional computational burden. The case of two intersections, allowing for the possibility of blocked vehicles as well, is presented in (Geng & Cassandras, 2014).

Another crucial observation is that the IPA estimator depends only on events which are observable in the actual intersection; for example, event E is simply the condition [$x_n = 0$ from above], i.e. an event representing the fact that a road queue becomes empty. In other words, even though the IPA estimator is derived from our stochastic flow model (15)-(16), its implementation is driven entirely by actually observed events in the real intersection.

Simulation Results

We briefly describe how the IPA estimator derived above can be used to adaptively determine optimal light cycles for an intersection we have simulated as a discrete event system, driven by actual data from an observed sample path of this system. We assume cars arrive according to a Poisson process with rate α_n, but emphasize again that the random vehicle arrival processes need not be constrained in any way. To simulate the real car departure process, whenever a GREEN cycle starts, we set the first car's departure rate to be β_n, uniformly distributed in [$\beta_{\min}$, $\beta_{\max}$]. The remaining cars in this GREEN cycle are processed at the same rate. We also constrain θ_i, $i = 1,2$, to take values in [$\theta_{\min}$, $\theta_{\max}$].

For the simulated model, we use a brute-force (BF) method to find an optimal θ^*_{BF} : we discretize all feasible real values of θ_i and for each (θ_1, θ_2) integer pair we run 10 sample paths to obtain the average total cost. The value of θ^*_{BF} is the one generating the least average cost, to be compared to θ^*_{IPA} , the IPA-based method. Recall that in this method the only effort involved is to simply count the number of light switching events and obtain the arrival rate $\alpha_n(\xi_{n,m})$ at S events and departure rate $\beta_n(\tau_k)$ at each light switching event. In our simulations, we estimate $\alpha_n(\xi_{n,m})$ through N_a/t_w by counting car arrivals N_a over a time window t_w before or after $\xi_{n,m}$; $\beta_n(\tau_k)$ is similarly estimated.

We set all arrival and departure processes to be the same for all four roads with $\alpha_n = 1/4$, $n = 1,2,3,4$, $\theta_{\min} = 15$sec, $\theta_{\max} = 40$sec, and $T = 500$sec. We first fix the departure rate, i.e. $\beta_{\min} = \beta_{\max} = 1$. In Fig. 6, we set $w = [0.4, 0.1, 0.4, 0.1]$, placing more emphasis on roads 1,3. We get $J^*_{IPA} = [22.01, 15]$, which is close to $\theta^*_{BF} = [24, 16]$, and associated costs $J^*_{IPA} = 1.59$, $J^*_{BF} = 1.52$. This result is intuitive by allocating the longer GREEN cycle to the more important roads. We also illustrate the adaptivity of the IPA-based light cycle control in Fig. 7, where the trajectories of θ_1,θ_2 are shown and the arrival rate changes over time. We set w

Figure 6. IPA-based traffic light control with w = [0.4, 0.1, 0.4, 0.1]

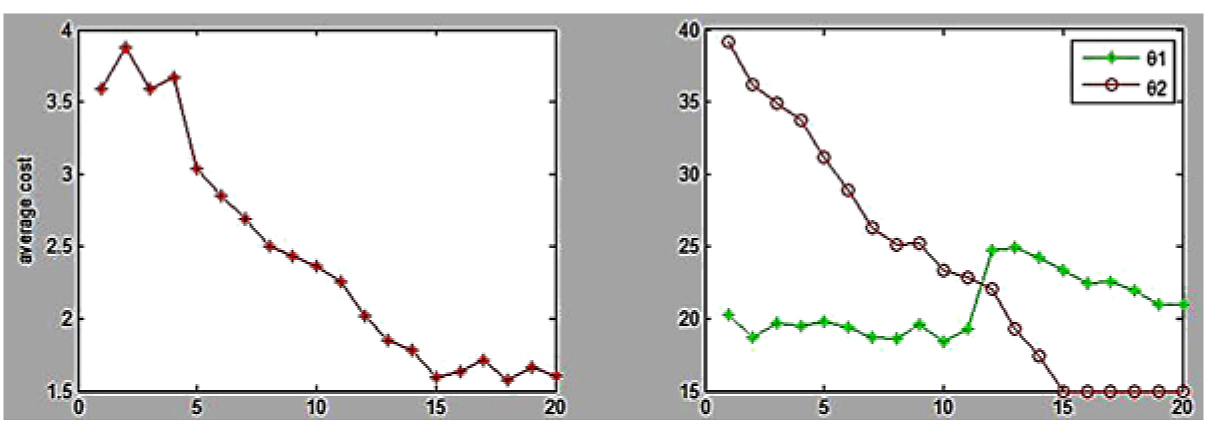
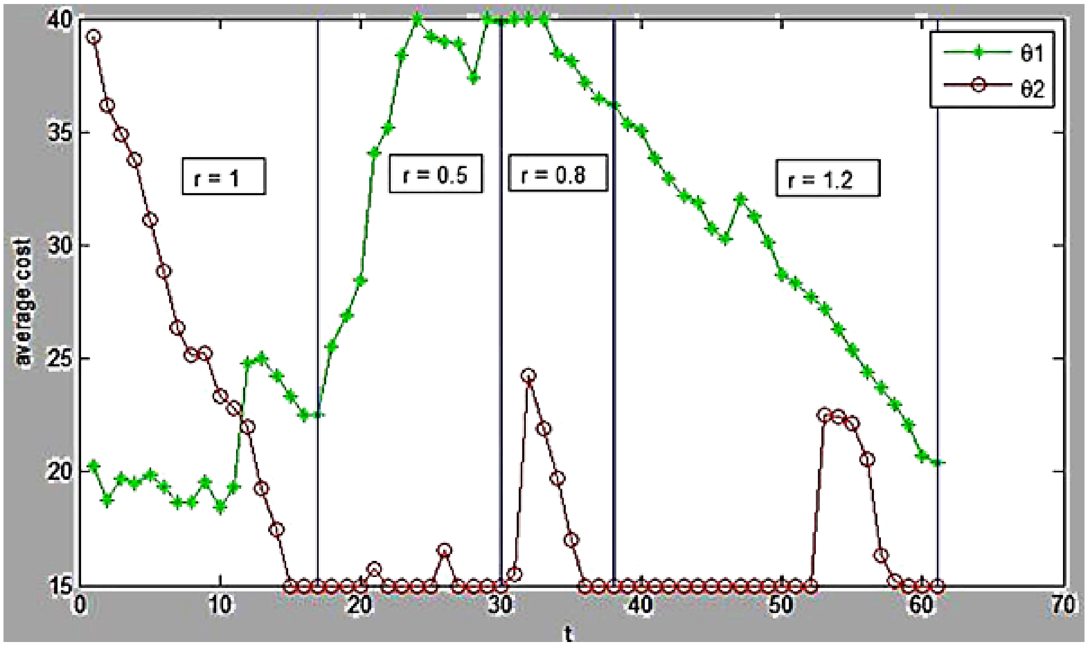


Figure 7. Adaptivity of light cycles using IPA when traffic varies



= [0.4, 0.1, 0.4, 0.1] and α_n = 1/(4r) where r changes where the vertical lines are seen in the figure. As we can see, θ_1,θ_2 respond to the rate changes by seeking new optimal values and converge to them.

CONCLUSION

Effective traffic control in a Smart City aims at minimizing congestion, hence also drastically reducing fuel consumption and pollution. New technologies in sensing and wireless networking, combined with advances in real-time control and optimization methodologies, provide the basis for achieving this goal through a variety of new transportation systems. In this chapter, we have described three such systems, starting with Smart Parking which exploits technologies for parking space availability detection and for driver localization and allocates and reserves optimal parking spaces to drivers instead of only supplying guidance to them. The determination of an efficient and optimal allocation strategy for both users and the system is based on solving a sequence of Mixed Integer Linear Program (MILP) problems which are guaranteed to have a feasible solution and to satisfy some fairness constraints. A pilot system is currently in operation at a Boston University parking facility. Using the same basic framework, we have also proposed a system for the optimal dynamic allocation of spaces for EVs at charging stations, including reserving these spaces. As with Smart Parking, this system exploits technologies for space availability detection and for EV localization. It also allocates charging station spaces to users instead of only supplying guidance to them.

Finally, by adopting stochastic hybrid system models for traffic flow control in an urban setting, we have formulated the basic Traffic Light Control (TLC) problem and applied IPA techniques in order to derive gradient estimates of a cost metric with respect to controllable light cycle lengths. By subsequently incorporating these estimators into a gradient-based optimization algorithm, we determine optimal light cycle lengths so as to significantly reduce traffic build-up (with respect to the traffic build up resulting from a system operating under static control). In fact, recent results reported in (Fleck & Cassandras, 2014) indicate that adaptive traffic light control policies provide 30-50% reductions in common congestion metrics relative to static methods with fixed cycles. This paves the way for extensions to a network of multiple intersections. Assuming that traffic lights can communicate with each other, it is also possible to endow a downstream light with the ability to predict an impending flow of vehicles and adjust its light cycle.

REFERENCES

Abdulhai, B., Pringle, R., & Karakoulas, G. (2003). Reinforcement learning for true adaptive traffic signal control. *Journal of Transportation Engineering*, *129*(3), 278–285. doi:10.1061/(ASCE)0733-947X(2003)129:3(278)

Alvarez, I., & Poznyak, A. (2010). Game theory applied to urban traffic light control problem. In *Proceedings of the International Conference on Control, Automation and Systems* (pp. 2164-2169).

Arnott, R., Rave, T., & Schob, R. (2005). *Alleviating urban traffic congestion*. Cambridge, MA: MIT Press.

Bazzan, A. L. (2009). Opportunities for multiagent systems and multiagent reinforcement learning in traffic control. *Autonomous Agents and Multi-Agent Systems*, *18*(3), 342–375. doi:10.1007/s10458-008-9062-9

Braess, D., Nagurney, A., & Wakolbinger, T. (2005). On a paradox of traffic planning. *Transportation Science*, *39*(4), 446–450. doi:10.1287/trsc.1050.0127

Cassandras, C. G., & Geng, Y. (2014). Optimal dynamic allocation and space reservation for electric vehicles at charging stations. In *Proceedings of 19th IFAC World Congress* (pp. 9611-9616).

Cassandras, C. G., & Lafortune, S. (2008). *Introduction to Discrete Event Systems*. New York, NY: Springer. doi:10.1007/978-0-387-68612-7

Cassandras, C. G., Wardi, Y., Melamed, B., Sun, G., & Panayiotou, C. G. (2002). Perturbation analysis for on-line control and optimization of stochastic fluid models. *IEEE Transactions on Automatic Control*, *47*(8), 1234–1248. doi:10.1109/TAC.2002.800739

Cassandras, C. G., Wardi, Y., Panayiotou, C. G., & Yao, C. (2010). Perturbation analysis and optimization of stochastic hybrid systems. *European Journal of Control*, *6*(6), 642–664. doi:10.3166/ejc.16.642-661

Choi, W., Yoon, H., Kim, K., Chung, I., & Lee, S. (2002). A traffic light controlling flc considering the traffic congestion. In *Proceedings of the AFSS International Conference on Fuzzy Systems* (pp. 69-75). doi:10.1007/3-540-45631-7_10

Chou, S., Lin, S., & Li, C. (2008). Dynamic parking negotiation and guidance using an agent-based platform. *Expert Systems with Applications*, *35*(3), 805–817. doi:10.1016/j.eswa.2007.07.042

DeSchutter, B. (1999). Optimal traffic light control for a single intersection. In *Proceedings of the American Control Conference* (pp. 2195-2199).

Dong, C. (2004). Area traffic signal timing optimization based on chaotic and genetic algorithm approach. *Computer Engineering and Applications*, *40*(29), 32–34.

Dong, C. (2006). Chaos-particle swarm optimization algorithm and its application to urban traffic control. *International Journal of Computer Science and Network Security*, *61*(1), 97–101.

Dong, C., Liu, Z., & Qiu, Z. (2005). Urban traffic signal timing optimization based on multi-layer chaos neural networks involving feedback. In *Proceedings of the First International Conference on Natural Computation* (pp. 340-344). doi:10.1007/11539087_41

Dressler, F., Hartenstein, H., Altintas, O., & Tonguz, O. K. (2014). Inter-vehicle communication-Quo Vadis. *IEEE Communications Magazine*, *52*(6), 170–177. doi:10.1109/MCOM.2014.6829960

Dujardin, Y., Boillot, F., Vanderpooten, D., & Vinant, P. (2011). Multiobjective and multimodal adaptive traffic light control on single junctions. In *Proceedings of the IEEE International Conference on Intelligent Transportation Systems* (pp. 1361-1368). doi:10.1109/ITSC.2011.6082977

Findler, N. V., & Strapp, J. (1992). A distributed approach to optimized control of street traffic signals. *Journal of Transportation Engineering*, *118*(1), 99–110. doi:10.1061/(ASCE)0733-947X(1992)118:1(99)

Findler, N. V., Surender, S., & Catrava, S. (1997). On-line decision about permitted/protected left-hand turns in distributed traffic signal control. *Engineering Applications of Artificial Intelligence*, 10.

Fleck, J. L., & Cassandras, C. G. (2014). Infinitesimal perturbation analysis for quasi-dynamic traffic light controllers. In *Proceedings of the 12th International Workshop on Discrete Event Systems* (pp. 235-240).

Fu, M. C., & Howell, W. C. (2003). Application of perturbation analysis to traffic light signal timing. In *Proceedings of 42nd IEEE Conference on Decision and Control* (4837-4840). doi:10.1109/CDC.2003.1272360

Gartner, N. H., Pooran, F. J., & Andrews, C. M. (2002). Implementation and field testing of the OPAC adaptive control strategy in RT-TRACS. *Journal of the Transportation Research Board*, 148-156.

Geng, Y., & Cassandras, C. G. (2012a). Multi-intersection traffic light control using infinitesimal perturbation analysis. In *Proceedings of 11th International Workshop on Discrete Event Systems* (pp. 104-109).

Geng, Y., & Cassandras, C. G. (2012b). Traffic light control using infinitesimal perturbation analysis. In *Proceedings of 51st IEEE Conference on Decision and Control* (pp. 7001-7006). doi:10.1109/CDC.2012.6426611

Geng, Y., & Cassandras, C. G. (2013). A new "Smart Parking" system based on resource allocation and reservations. *IEEE Transactions on Intelligent Transportation Systems*, *14*(3), 1129–1139. doi:10.1109/TITS.2013.2252428

Geng, Y., & Cassandras, C. G. (2014). Multi-intersection traffic light control with blocking. *Journal of Discrete Event Dynamic Systems*. Preprint at http://link.springer.com/article/10.1007/s10626-013-0176-0#page-1

Griffith, E. (2000). Pointing the way. *ITS International, 72.*

Head, L., Ciarallo, F., & Kaduwela, D. L. (1996). *A perturbation analysis approach to traffic signal optimization*. Paper presented at the 1996 INFORMS National Meeting.

Henry, J., Farges, J., & Gallego, J. (1998). Neuro-fuzzy techniques for traffic control. *Control Engineering Practice*, *6*(6), 755–761. doi:10.1016/S0967-0661(98)00081-1

Henry, J. J., & Farges, J. (1990). *PRODYN control, computers, communications in transportation*. Oxford, UK: Pergamon Press.

Hodel, T. B., & Cong, S. (2003). Parking space optimization services, a uniformed web application architecture. In *Proceedings of Intelligent Transport Systems and Services, ITS World Congress* (pp. 16-20).

Hunt, P. B., Robertson, D. L., & Bretherton, R. D. (1982). The SCOOT on-line traffic signal optimization technique. *Traffic Engineering & Control*, *23*, 190–192.

Little, J., Kelson, M. D., & Gartner, N. H. (1981). Maxband: A program for setting signals on arteries and triangular networks. *Transportation Research Record*, *795*, 40–46.

Liu, Z. (2007). A survey of intelligent methods in urban traffic signal control. *International Journal of Computer Science and Network Security*, *7*(7), 105–112.

Lowrie, P. (1982). The Sydney co-ordinated adaptive traffic system - principles, methodology, algorithms. In *Proceedings of the IEE Conference on Road Traffic Signaling* (pp. 67-70).

Mimbela, L., & Klein, L. (2000). *A summary of vehicle detection and surveillance technologies used in intelligent transportation systems*. Retrieved September 2014 from http://ntl.bts.gov/lib/10000/10000/10041/029prs.pdf

Panayiotou, C. G., Howell, W. C., & Fu, M. C. (2005). Online traffic light control through gradient estimation using stochastic flow models. In *Proceedings of 2005 IFAC Triennial World Congress*.

Pappis, C., & Mamdani, E. (1977). A fuzzy logic controller for a traffic junction. *IEEE Transactions on Systems, Man, and Cybernetics*, *7*(10), 707–717. doi:10.1109/TSMC.1977.4309605

Porche, I., Sampath, M., Sengupta, R., Chen, Y. L., & Lafortune, S. (1996). A decentralized scheme for real-time optimization of traffic signals. In *Proceedings of IEEE International Conference on Control Applications* (pp. 582-589). doi:10.1109/CCA.1996.558925

Prashant, L. A., & Bhatnagar, S. (2011). Reinforcement learning with function approximation for traffic signal control. *IEEE Transactions on Intelligent Transportation Systems*, *12*(2), 412–421. doi:10.1109/TITS.2010.2091408

Robertson, D. I. (1969). TRANSYT method for area traffic control. *Traffic Engineering & Control*, *10*, 276–281.

Rodier, C. J., & Shaheen, S. A. (2010). Transit-based smart parking: An evaluation of the San Francisco bay area field test. *Transportation Research Part C, Emerging Technologies*, *18*(2), 225–233. doi:10.1016/j.trc.2009.07.002

Sen, S., & Head, L. (1997). Controlled optimization of phases at an intersection. *Transportation Science*, *31*(1), 5–17. doi:10.1287/trsc.31.1.5

SFPark. (2012). *Parking sensor data feed specification*. Retrieved from http://sfpark.org

Shelby, S. G., Bullock, D. M., Gettman, D., Ghaman, R. S., Sabra, Z. A., & Soyke, N. (2008). Overview and performance evaluation of ACS Lite - a low cost adaptive signal control system. In *Proceedings of 87th Annual Meeting of the Transportation Research Board*.

Shoup, D. (2005). *The high cost of free parking*. Chicago, IL: APA Planner Press.

Spall, J. C., & Chin, D. (1997). Traffic-responsive signal timing for system wide traffic control. *Transportation Research Part C, Emerging Technologies*, *5*(3), 153–163. doi:10.1016/S0968-090X(97)00012-0

Streetline (2012). *Streetline: Connecting the Real World*. Retrieved from http://www.streetlinenetworks.com

Teodorovic, D., & Lucic, P. (2006). Intelligent parking systems. *European Journal of Operational Research*, *175*(3), 1666–1681. doi:10.1016/j.ejor.2005.02.033

Thompson, R. G., & Bonsall, P. (1997). Driver's response to parking guidance and information systems. *Transport Reviews*, *17*(2), 89–104. doi:10.1080/01441649708716974

Thompson, R. G., & Richardson, A. J. (1998). A parking search model. *Transportation Research*, *33*, 159–170.

Tsai, M., & Chu, C. (2012). Evaluating parking reservation policy in urban areas: An environmental perspective. *Transportation Research Part D, Transport and Environment*, *17*(2), 145–148. doi:10.1016/j.trd.2011.10.006

Wardi, Y., Adams, R., & Melamed, B. (2010). A unified approach to infinitesimal perturbation analysis in stochastic flow models: The single-stage case. *IEEE Transactions on Automatic Control*, *55*(1), 89–103. doi:10.1109/TAC.2009.2034228

Waterson, B. J., Hounsellm, N. B., & Chatterjee, K. (2001). Quantifying the potential savings in travel time resulting from parking guidance systems - a simulation case study. *The Journal of the Operational Research Society*, *52*(10), 1067–1077. doi:10.1057/palgrave.jors.2601207

Wen, W., & Hsu, H. W. (2006). A dynamic and automatic traffic light control system for solving the road congestion problem. *WIT Transactions on the Built Environment*, *89*, 307–316.

Wen, Y., & Wu, T. (2005). Reduced-order rolling horizon optimization of traffic control based on ant algorithm. [Engineering Science]. *Journal of Zhejiang University*, *39*(6), 835–839.

Wey, W. M. (2000). Model formulation and solution algorithm of traffic light control in an urban network. *Computers, Environment and Urban Systems*, *24*(4), 355–377. doi:10.1016/S0198-9715(00)00002-8

Wiering, M., Vennen, J., & Koopman, A. (2004). *Intelligent traffic light control*. Retrieved from http://dspace.library.uu.nl/handle/1874/17996

Young, W., Thompson, R., & Taylor, M. (1991). A review of urban car parking models. *Transport Reviews*, *11*(1), 63–84. doi:10.1080/01441649108716773

Zhao, X., & Chen, Y. (2003). Traffic light control method for a single intersection based on hybrid systems. In *Proceedings of IEEE International Conference on Intelligent Transportation Systems* (pp. 1105-1109).

KEY TERMS AND DEFINITIONS

Cyber-Physical Systems: Systems consisting of physical components whose operation is controlled by embedded networked computational elements.

Dynamic Resource Allocation: A systematic procedure for allocating resources to mobile users in a time-varying environment.

Electric Vehicles: Vehicles powered by electric motors as opposed to fossil-fuel-based technologies.

Perturbation Analysis: A data-driven methodology for estimating the sensitivity of a dynamic system's state with respect to various parameters.

Smart Parking: The process of providing drivers real-time information on the state of parking resources in a given area, directing them to the best available parking space based on their destination and cost preferences, and ensuring that this space is reserved for them.

Stochastic Hybrid Systems: Stochastic systems combining time-driven dynamics (usually modeled through differential equations) with event-driven dynamics (usually involving discrete event system models).

Traffic Light Control: The process of dynamically controlling green and red traffic light durations so as to optimize specific performance criteria, typically measuring vehicle waiting times.

Transportation Systems: Systems designed to accommodate the movement of vehicles through roadway networks.

Chapter 12
Smart, Sustainable, and Safe Urban Transportation Systems:
Recent Developments in the Asia-Pacific Region

Hoong-Chor Chin
National University of Singapore, Singapore

Yueying Wang
National University of Singapore, Singapore

ABSTRACT

One of the fastest growing areas in the world is the Asia-Pacific region. With anticipated acceleration in motorization and potentially-damaging unplanned urban sprawl, the region will be threatened by problems of traffic congestion, pollution and road hazards. Several countries in the region have taken a variety of proactive measures to ensure that the urban transportation systems are designed and operated in a smart, sustainable and safe manner. This chapter identifies the policies and practices in South Korea, Japan, China, Taiwan, Singapore and Australia, and seeks to draw lessons from these on how transportation schemes can be implemented elsewhere in Asia.

INTRODUCTION

One of the fastest growing areas in the world is the Asia-Pacific region, accounting for about 40% of global growth and one-third of global trade in 2013. Rapid economic growth and the large population base mean that the demand for transportation in the domestic sector, particularly in urban areas, is expected to rise in tandem. The World Bank estimates that in the next decade, the region will attract some additional 500 million residents, with more than half of these in urban areas. With anticipated acceleration in motorization and potentially-damaging unplanned urban sprawl, the region will be threatened by problems of traffic congestion, pollution and road hazards.

Yet several countries in the Asia-Pacific Region have taken on a variety of proactive measures to ensure that urban transportation systems are designed and operated in a smart, sustainable and

DOI: 10.4018/978-1-4666-8282-5.ch012

safe manner. This chapter identifies the urban transportation policies and practices in South Korea, Japan, China including Hong Kong SAR, Taiwan, Singapore and Australia, and seeks to draw lessons from these to establish whether and how these transportation schemes can be implemented elsewhere in Asia.

These practices will be examined following 3 components: smart urban transportation, sustainable urban transportation and safe urban transportation.

Overview of Asia-Pacific Countries

The Asia-Pacific Region generally comprises countries in East Asia (China, Hong Kong SAR, Japan, Republic of Korea and Taiwan), Southeast Asia (Brunei, Cambodia, Indonesia, Loa People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam) and Oceania (Australia, New Zealand and the Pacific Islands).

For the purpose of this chapter, seven Asia-Pacific countries (including Hong Kong SAR) are examined. They represent a wide range of population sizes, per capita GDP and degree of urbanization. Singapore has a population of only 5.3 million, which with a 100% urbanized land mass gives a population density of 7,300 people per km^2. It enjoys a per capita GDP of US$50,000 which is projected to increase at a rate of 5.5% in 2014. On the other hand, China has a population of 1.35 billion with 50% urbanization along with a per capita GDP of US$5,900 which is projected to grow at 8.2%.

SMART URBAN TRANSPORTATION

Worldwide, smart urban transportation has been progressively developed with improvements in the following aspects:

1. Sensor technologies, including the use of cameras, lasers and Radio Frequency [RF] sensing and interaction with imaging technologies;
2. Control systems with enhanced sensing technologies, to promote autonomous functions particularly within vehicles;
3. Processing capabilities with supercomputers processing large amounts of data and advanced analytics for big data, offering real-time, responsive solutions;
4. Communication technologies including mobile network technologies, allowing greater use of ubiquitous devices, resulting in more flexible and personal travel choices.

Naturally such systems, championed as Intelligent Transport Systems [ITS], are more likely to be found in the highly urbanized, more developed major cities, like Singapore, Tokyo, Hong Kong and Seoul, where there is a high level of mobile network connectivity. While advanced technologies have been long employed in managing transportation in many Asian Pacific cities, modern sensor devices and their integration in vehicle-to-vehicle [V2V] and vehicle-to-infrastructure [V2I] systems are primarily confined to countries with strong research and development in the automobile industry, such as Japan, and increasingly in Korea and China. There is therefore considerable scope for smart transportation applications in Asian Pacific cities.

Early Developments in Smart Transport in Asia-Pacific Area

A number of developed nations, like Japan, Australia and Singapore, have initiated smart traffic control systems since the 1970s. In 1973, Japan first established the traffic control center on the Metropolitan Expressway marking the start of the nation's ITS era (Ministry of Land, Infrastructure, Transport and Tourism, 2012). Vehicle navigation systems were introduced in the early 1980s, but the breakthrough in the V2I systems came in 1996 when the *Vehicle Information and Communication System* [VICS] was established to broadcast current traffic conditions to vehicles to allow real-time navigation throughout all inter-city and urban roads in Japan. In the 1970s, Australia developed the *Sydney Coordinated Adaptive Traffic System* [SCATS] to monitor real-time traffic flows and coordinate traffic signals in the Sydney area. The SCATS has since been in use in numerous cities outside Australia, for instance in Hong Kong, Singapore and a number of cities in China (Tyco Traffic & Transportation, 2014). In the last two decades, the rapid increase in urban travel has led many cities to deploy smart technologies (see Figure 1) to develop innovative solutions to urban transport problems.

In the area of public transport, information regarding train arrivals has been widely used and clearly displayed on station information boards for a number of years. Information on bus arrivals is generally more difficult to furnish, although bus schedules were available electronically for some years. In the 1980s, the location of city buses in Kyoto (Japan) was indicated at downstream bus stops by detecting the presence of buses using overhead ultrasonic detectors at upstream bus stops. Mobile communications and better vehicle sensing technologies have now made bus arrivals more precise and in turn, applications furnishing travelers with route planning on public transport, including inter-modal transfers, are now seen in major cities like Seoul and Taipei, and nationwide in Japan.

Figure 1. Display on an onboard navigational device supported by VICS in Japan
(Source: photo taken by the author)

Smart Transport Infrastructure

Transport infrastructure forms an important part of any transportation system, particularly in the areas of monitoring and control. Smart technologies have been introduced to enhance these functions, in particular with regard to traffic management and toll collection.

In Japan, by providing real-time road traffic information to drivers via in-car navigation equipment, VICS has helped to shorten travel times and reduce driving-related stress. The service which is available 24/7 throughout Japan, collates roadside information such as congestion levels, travel restrictions, and parking space availability via seven national VICS centres, and transmits this information via radio beacons on highways, light beacons on the major normal roads, and FM multiple broadcasts. The massive infrastructure project was achieved through the excellent coordination and agreement of numerous stakeholders, including vehicle manufacturers, highway authorities and equipment providers (Highway Industry Development Organization, 2004). The capability of the VICS has been well demonstrated in the aftermath of the recent Great East Japan Earthquake when probe data and road closure information were beamed to help vehicles find passable routes (Ministry of Land, Infrastructure, Transport and Tourism, 2012).

Following the Seoul 1998 Olympics when the city transport infrastructure was enhanced, South Korea expanded the Advanced Traffic Management System [ATMS] nationwide. In this system, real-time traffic information collected through inductive loops, closed-circuit cameras and vehicle probe data in 79 municipal transport authorities are consolidated at the *National Transport Information Center* [NTIC] which then provides information to travelers through variable message signs [VMS], mobile phones, vehicle navigation devices, the Internet, and the Traffic Broadcasting Station (Korea Expressway Corporation, 2009). At present, the ATMS covers all expressways, 14% of national highways and 25 major cities in South Korea (National Transport Information Center, 2014), and it is estimated that it contributes about 146.2 billion South Korean Won (US$131 million) to annual savings in terms of reduced transport time, accidents and environmental pollution (Institute for Transportation & Development Policy, 2013).

Beside Traffic Management System, Electronic Toll Collection [ETC] is another key ITS product. Since 1997, the ETC system has been in use on major highways in Japan, either as a point-charge or distance-based charge. The usage rate of the electronic system is 87% and this has virtually eliminated all toll-gate congestion on expressways, which previously contributed to 30% of all expressway delays (Hollborn, 2002). Known as the world's first active-frequency and infrared integrated system, South Korea's *Hi-Pass* ETC system covers 50% of highways (Ezell, 2010) and is used by 50.8% of vehicles (Lee, 2012). The *Hi-Pass* card can also be used for other electronic purchases including parking, fuel payment, and purchases at convenience stores. Similar ETC systems have also appeared on intercity highways around several mega cities in China, such as Shanghai (Tan, 2012), Guangzhou (Wu et al., 2009) and Beijing (Ou, 2013). In Taiwan, the ETC service is used on toll roads under a build-operate-transfer project (Chou, 2011). On the other hand, Hong Kong has conducted feasibility studies and is putting on trial a similar system on the Central Wan Chai bypass. The *Electronic Road Pricing* [ERP] scheme in Singapore (see Figure 2), which was put in place in 1998 to replace the 20-year-old manual cordon pricing scheme (Lew & Ang, 2010), differs from the highway toll system in that it is tweaked to charge different rates depending on location and the level of expected congestion, segmented by time of day and day of the week (Foo, 2000). Currently, a large-scale trial is underway to use the Global Navigation Satellite System [GNSS] instead of physical gantries for toll transactions, which is due to replace the point-charge system by a distance-based system (Haque et al., 2013).

Figure 2. Singapore is looking into upgrading the current ERP technology with a GPS-based ERP system
(Source: photo taken by the author)

However, this may give rise to privacy concerns, as vehicle movements within the city can be easily tracked in this way.

Smart Vehicle Technology

With a major automobile industry, Japan has a long history of research and development in vehicle technology. Toyota, Honda, Mazda and Nissan have developed modern smart vehicles with multiple sensors for intelligent parking and driving. Smart cars with control functions including lane-keeping, pre-crash safety and advanced cruise control, are now common in the Japanese market (Kato, 2002). In-vehicle cameras help to detect lane departures, to determine the appropriate amount of steering required, and to maintain the vehicle in its lane. Millimetre-wave radar can detect the vehicle and obstacle ahead and assist the brake action earlier and lower the collision speed. Vehicles equipped with adaptive cruise control [ACC] sensors work together with the road infrastructure, such as ITS spots designed to mitigate sag-congestion (Ministry of Land, Infrastructure, Transport and Tourism, 2012). Furthermore, manufacturers of automobile navigation systems and on-board units [OBU] have worked together to produce ITS spot-compatible systems, and 10 million of such OBUs have been sold in the last five years.

The concept of micro mobility has also been developed, with personal mobility vehicles such as micro electric vehicles [MEV] designed to enhance the mobility of elderly people and to facilitate first- and last-mile travel (Ministry of Land, Infrastructure, Transport and Tourism, 2013a). For vehicle parking purposes, many car manufacturers have provided intelligent sensors from the basic ultrasonic wave sensors that detect the distance to object, and rear cameras that display the rear view during vehicle reversing mode, to the most advanced and integrated system called *Intelligent Parking Assist*, that automatically takes over control of the steering wheel according to the parking position (Toyota, 2014).

Taxis in several cities like Singapore and Tokyo have also installed GPS and wireless communication systems to facilitate efficient passenger bookings. Recently, apps on smart phones for taxi booking have become very popular, such as *All Japan Taxi Dispatch* in Japan, *GrabTaxi* in Singapore, *Jiaochetong* in Taiwan, and *Didi Dache* and *Kuaidi Dache* in China. However, the abundance of such apps is also causing confusion and concern among taxi drivers in some Chinese cities, especially when chat apps have been integrated with payment apps, e.g. *WeChat* with *Didi Dache,* and *Kuaidi Dache* with *Alipay*.

Smart vehicle technologies have also been used in freight transportation for the purposes of fleet management and planning in city logistics. In vast Australia, the road freight industry has been investing in in-vehicle telematics which enable freight operators to monitor and manage their freight movements and deliveries, as well as the authorities for the purpose of regulating vehicle loading and driver performance (Hocking, 2010; National Transport Commission, 2011). Similarly, South Korea has the Advanced Freight System which requires a tag and Dedicated Short Range Communication [DSRC] system on board commercial vehicles, that is able to support multiple services such as electronic clearance, international border clearance, and safety monitoring under the *Korea Integrated Logistics Information Systems* [ILIS] (Kang & Kim, 2001).

Smart Public Transport Systems

Information about vehicle location is readily available on services with fixed guide-ways, such as trains. With improved sensor technology, Advanced Public Transportation Systems [APTS] that allow details of the "next bus" to be displayed at bus stops are now available in many Asian cities. In Seoul, about 300 bus stops are connected to the central traffic operations center by wireless communications to allow an integrated, up-to-the-second view of Seoul's bus transportation network (Ezell, 2010). Taiwan has similar *Convenient Public Transport Information Services* (Chou, 2011). Such information may also be available from bus stops on Internet sites, e.g. the integrated public transport map and mobile travel advisor for train and bus arrivals in Singapore (Haque et al., 2013), as well as *eTransport* in Hong Kong. In Japan, the pre-planning of inter-modal trips, including the *shinkansen* (bullet train), intercity trains, subways, buses and even air links, has long been available nationwide on the *hyperdia* platform where details of travel times, fares, transfer locations are updated in real time (see Figure 3).

The features of ADTS also include a unified smart fare card system or electronic fare payment system, which is available in many cities in Asia, allowing easy intermodal transfers often with the capability to compute and charge the exact cost of the entire journey rather than that of individual trip segments. Many of these pre-paid smart cards, such as *EZ-link* in Singapore have also been expanded for non-travel transactions at stores, restaurants and parking garages. The Octopus card in Hong Kong also serves as an access ID in schools, office buildings and residential buildings. Some of the systems are recognized nationwide, e.g. T-money is acceptable throughout South Korea, and the *Suica*

Figure 3. Real-time arrival information at a tram stop in Melbourne
(Source: photo taken by the author)

(Super Urban Intelligent Card) throughout Japan including on the nation's many private railway lines. Along with the Suica card, Japan also issues a number of regional pre-paid intelligent cards, e.g., *PASMO*, *ICOCA* and *MIOCA*. Singapore's *EZ-Link* and Taiwan's *EasyCard* have recently announced a common *Cross Border Combi Card* that can be used in the two countries to pay for public transport and various attractions (Leong, 2014). This initiative involving transactions in two currencies will incentivize the development of a common smart card to be used for multi-national and multi-currency transactions.

Another application of smart technology is the bus rapid transit [BRT] system, which offers high-quality, customer-oriented public transport that is fast, safe, comfortable, reliable and cost effective (Levinson et al., 2003). One good example of this is the Seoul BRT system which serves as an effective, less expensive complement to the main metro lines. To achieve this, the entire bus network of 400 bus routes was redesigned in 2004 and the BRT system was supplemented by dedicated median bus lanes, high-quality median bus stops and real-time information for passengers, together with a new Bus Management System based on ITS technology (Pucher et al., 2005).

The Lessons Learned and the Challenges Ahead in the Field of Smart Transportation

The foregoing discussion highlighted the many developments in smart transportation in the Asia-Pacific Region. Despite this wave of change sweeping across the region, there are still challenges that need to be addressed. The planning of a smart transportation system requires a clear vision, long-term commitment and realistic implementation plans.

Funding of Smart Transportation Projects

A major challenge in developing smart transportation systems in any city or region is how these projects are to be funded. Most transportation infrastructure projects are costly, and while it may seem reasonable to expect some funding to be forthcoming from national or local government, it may prove too much of a burden on government which may well have a host of other political

Figure 4. The accelerated implementation of the BRT system in Guangzhou in time for the 2010 Asian Games
(Source: photo taken by the author)

priorities to address. System providers including vehicle manufacturers are likely to have invested in product development, and are likely to expect government to provide some of the funding for such. Ultimately the end users will have to bear a substantial part of the cost, whether through taxes or payment for services received. Some of the smart transportation projects get a boost when they are planned as part of a major event, like the Olympics in Seoul and Beijing, or the Asian Games in Guangzhou (see Figure 4). Besides offering an integrated approach to planning, such an arrangement can also benefit from the overall economic evaluation involved.

Standardisation of Technical Specifications

Within the Asia-Pacific or Asian region, there is little cooperation among countries in the development of smart technologies. Standardisation is an important factor if multi-national cooperation and the coordination of ITS systems are to be achieved. One area of concern is the use of frequency bands for communications dedicated for transport purposes. Besides bandwidth, there are also hardware compatibilities, all of which require the development of technical specifications and standards. In the absence of regional standardization bodies such as those existing in Europe, the region is likely to rely on local standards for smart transportation. The alternative is to move towards adopting UN standards, which will require the Asia-Pacific countries to be sufficiently represented on international standards committees.

Security and Privacy in Information Usage

Despite the many benefits of ITS, the increased dependence on vehicle/infrastructure electronics and communications also raises concerns with regard to security and privacy. Smart transportation systems rely heavily on information sharing. The possibility of linking private information to supposedly non-confidential information such as location, may not be easily managed especially when there are many service providers involved. It is a major challenge to ensure the integrity, confidentiality and secure handling of data, including the disclosure of personal and financial details. Unlike their North American and European counterparts, Asians may be less prepared for such intrusion when embracing the new technologies.

SUSTAINABLE URBAN TRANSPORTATION

Sustainable transportation can be loosely defined as a set of transport operations and the corresponding infrastructures that collectively do not leave problems or costs for future generations to solve or bear, that is, the present implementers and users of the transportation system should bear the costs thereof today (Clean Air Initiative for Asian Cities, 2006).

Promoting sustainable transport systems has proven a major challenge for local governments in many cities in Asia and the Pacific region for various reasons. In most developing countries, there is a lack of political will, vision and coordination on the part of a wide range of stakeholders, made worse by the insufficient technical capacity to design and implement suitable policies. Often, transport issues are tackled as a distinct entity rather than as a part of an integrated approach to urban planning.

Three aspects of sustainability are pursued in urban transportation planning and operations, namely environmental, economic and equitable sustainability (Jeon & Amekudzi, 2005). This three-dimensional framework for sustainability, such as the issues of environment preservation, economic development, and social development in Asia-Pacific countries, will be discussed in the following sections.

Environmentally Sustainable Transportation

To be environmentally sustainable, transportation should not endanger public health or any ecosystem. As the major concern in transportation involves emissions, which are directly linked to the reliance on fossil fuels in vehicles' internal combustion engines, measures to ensure improved environmental sustainability include: (1) the control of emissions through higher emission standards, and the use of alternative fuels in internal combustion engines; (2) the redesign of vehicle engines to support electric vehicles [EVs] or hybrids; and (3) the promotion of eco-friendly travel through improved driving habits or the use of green transport modes.

The setting of higher emission standards varies somewhat throughout the Region. Despite its lengthy history of support for fuel efficiency standards, Japan's latest emission standard was only tightened in 2009, to a level between *US 2010* and *Euro V* requirements (DieselNet, 2007). This was later revised to match the highest international level for passenger cars by 2020 (Kajiwara, 2012). Singapore will also impose the more stringent *Euro IV* emission standard for all vehicles, and the *Euro V* standard for diesel vehicles, by the year 2020 (Ministry of Finance, 2013). In 2005, South Korea began enforcing a fuel economy rating scheme to stimulate car manufacturers to invest in the promotion of fuel-efficient vehicles. It adopted *California's Non Methane Organic Gases* (NMOG) *Fleet Average System* (FAS) for gasoline-fueled vehicles, and diesel emissions standards based on *Euro VI* values (TransportPolicy.net, 2013). In China, *Euro IV* standards took effect in 2010, although Beijing, as the leading city, first adopted such standards in 2008. With a growing automobile industry, China has also proposed a fuel-consumption target of 5litre/100km for all new passenger cars by 2020 (He, 2013). On the other hand, in 2006 Hong Kong imposed the requirement that all new passenger cars must meet the *Euro IV* standard.

Of all the Asian Pacific countries, perhaps Japan has been the most aggressive in promoting the use of eco-vehicles and eco-driving. Home to several major vehicle manufacturers, Japan has developed and extensively promoted EVs so that as of December 2013, the Japanese fleet of plug-in EVs is the second largest in the world after that of the USA (Cobb, 2014). The Japanese government has provided financial subsidies, loans and tax breaks to promote the use of eco-cars, which include electric and fuel-cell vehicles, as well as vehicles powered by alternative sources of energy such as natural gas, methanol and liquefied petroleum gas [LPG] (Ministry of Environment, 2008). This has led to a gradual increase in the proportion of eco-cars in the nation's vehicle fleet (Japan Automobile Manufacturers Association, 2012). With projected next-generation cars making up 50% of new car sales, emission cuts in the transportation sector would account for a total reduction of about 20% in all carbon dioxide emissions in Japan (Ministry of Land, Infrastructure, Transport and Tourism, 2009).

Meanwhile, South Korea has developed an *Online Electric Vehicle* [OLEV] that can be charged, whether stationary or in motion, using electromagnetic induction to minimize the need to stop at a charging station. Launched by The Korea Advanced Institute of Science and Technology [KAIST], a public transport system using a "recharging road" uses its battery only in an emergency when it is impossible to supply electric power, thus allowing battery capacity to be reduced to that of existing electric vehicles (Korea Advanced Institute of Science & Technology, 2013). The Chinese government has also implemented purchase incentives in 2010 in order to promote the sales of new energy vehicles [NEVs] which comprise pure electric vehicles together with plug-in hybrid electric vehicles (PRTM, 2011). A trial program has been launched in five Chinese cities, whereby vehicle manufacturers are provided with subsidies as an indirect way of lowering vehicle prices (Motavalli, 2010).

Various other measures have been implemented in Japan to promote eco-driving. In the Kyoto Protocol Goal Achievement Plan (Ministry of Environment, 2008), Japanese drivers are encouraged to leave engines idle when stopping or parking, and to drive at safe, constant speeds according to the traffic conditions. Among commercial vehicles, an *Eco-drive Management System* [EMS] has also been introduced for transport operators (Ministry of Environment, 2008). The commitment and involvement of the government, fleet operators, drivers and vehicle manufacturers, has contributed towards a greater awareness of the importance of eco-driving.

Other eco-friendly modes, such as cycling and walking, are being increasingly promoted in Japan, South Korea and China. Japan has developed a wide network of cycle-friendly routes comprising 2,660 km of cycle lanes, thus achieving a figure of 0.2% of cycle lane per road in 2007. Often cycle lanes are created by reducing the width of the corresponding vehicle lane. Furthermore, environmentally-conscious companies have encouraged their employees to shift from car commuting to cycling (Ministry of Environment and Ministry of Land, Infrastructure, Transport and Tourism, 2009). South Korea also has successfully introduced an extensive shared cycle network in cities like Changwon. Changwon is an excellent example of eco-mobility, having the largest *Public Bike Share System* in Korea (see Figure 5) deploying about 3,000 bicycles and 240 stations with an average bicycle mode share of 10% (Lee et al., 2012). In 2008, Hangzhou undertook the first bike-sharing program in China (Local Governments for Sustainability, 2011). The *Hangzhou Public Bicycle* system, which is funded entirely by the government, is the largest in the world given the city's large population and high density. Bicycle trips in Hangzhou account for 43% of all trips, with daily bike trips totaling 1.1 million km. This

Figure 5. Public bike share system in Changwon, South Korea, designed to promote eco-mobility
(Source: photo taken by the author)

success is largely due to the integration of cycling into the public transit system through a single fare card for subway travel, buses, ferries, taxis and bike sharing, thereby achieving a good first and last mile connection. Taiwan also opened a bike lane network in the Xinyi commercial district in 2009 (Taipei City Government, 2010) and a build-operate-transfer based program in Kaohsiung in 2010 (Ely & Brick, 2012).

Economically Sustainable Transportation

An efficient transportation system generally produces economic benefits, such as a reduction in the wastage of travel-related resources, the enhancement of business productivity, and a potential increase in employment and consumption opportunities. There are however concerns regarding the costs of environmental damage, the adverse impact on health, and the accidents of traditional modes of transport. Economic sustainability seeks to ensure that transportation projects are planned, and that resources are consumed in a manner that will promote economic growth in the long term.

There are some innovative examples of effective congestion management in the region. Policies restricting car ownership have been in place in Singapore and China for several years. Singapore introduced the *Vehicle Quota System* [VQS] in 1990; this system requires vehicle owners to bid for 10-year vehicle leases known as *Certificates of Entitlement* [COE] (Santos et al., 2004). This has resulted in extremely high costs associated with owning private vehicles. While this strategy may have increased economic efficiency from improved driver mobility, it may also have increased the economic cost of vehicle replacement as drivers tend to scrap their vehicles way ahead of their technical lifespan. In the face of rapid motorization and worsening traffic congestion, many Chinese cities have also instituted local policies to control car ownership and vehicle usage. Shanghai has a policy of limiting car ownership by a bid-auction mechanism for vehicle registration (Peng & Lu, 2012); while Beijing employs a "lottery" system to restrict the number of new car purchases (Peng & Lu, 2012). The Chinese method of controlling car ownership may be more sustainable from the economic viewpoint than the bidding system adopted in Singapore.

A more direct method of controlling congestion is through road pricing and car park pricing. Singapore has successfully managed congestion in the city for a number of years through a cordon pricing system implemented from 1975 to 1998, and an electronic road pricing system in place since 1998. The charging system has been gradually expanded from the initial 27 charging points within the central business district [CBD] to the current 74 throughout the country, and extended from peak hours initially to include non-peak and late evening periods. Most cities have imposed high parking fees within the CBD. For example, the parking fee for cars in Beijing's CBD was increased from an hourly 4 RMB (US$0.65) in 2002 to 15 RMB (US$2.43) in 2011 (Peng & Lu, 2012). In Singapore, hourly parking charges for cars in the CBD range from $2.00 (US$1.60) in public areas to $6.00 (US$4.80) in private developments. Tokyo charges ¥300 (US$2.50) per hour for on-street parking, although these lots are rather limited due to lack of road space for parking. By itself, high parking and road charges may not effectively deter vehicle usage within the CBD, but may only work well if a comprehensive public transport network is available, as in the case of many Japanese cities.

The lack of sustained funding for transportation infrastructure and services is a common problem in Asia-Pacific countries. Various financing models have been used. In China, urban transport projects are usually implemented through national revenues (Organisation for Economic Co-operation and Development, 2013). The city transportation projects were thus funded in Beijing as part of the Olympic Games in 2008, and in Shanghai as part of the World Expo in 2009. The Beijing Olympics accelerated plans to expand the Beijing subway system, with projects totaling 63.8 billion RMB (US$10.37 billion). Public-private partnership has been progressively adopted in the case of new projects, e.g. Beijing's Metro Line 4 was built through a public-private partnership between the Beijing Capital Group, Beijing Infrastructure Investment Co. Ltd. and Hong Kong MTR Corp (Pan, 2011). The bike sharing programs in China are funded in a variety of ways. The program in Beijing is operated by local private companies without cooperation with metro operators. The program in Shanghai was established and operated by a bicycle manufacturing company with the local government purchasing the service and renting the facilities on the basis of a 5-year contract. On the other hand, the bike program in Hangzhou was established by Hangzhou government with direct investment of 180 million RMB and discount government loans of 270 million RMB to be operated by a government-owned public transit company.

In Singapore, transportation infrastructures including public transport facilities are financed by the government, leaving operators to finance their operation and rolling stock. However, in a significant departure from the earlier model, the Land Transport Authority [LTA] launched the *Bus Service Enhancement Programme* [BSEP] in 2012, whereby the government will provide bus operators with funding of $1.1 billion (US$0.88 billion) for 550 new buses (PwC, 2013). Extending this further, the LTA is adopting a contract model in which the bus network is planned by the government, leaving bus operators to tender for operations. On the other hand, public-private partnerships have been quite successful in South Korea, accounting for a total of 82 transport infrastructure projects, costing 58.83 trillion KRW (US$53 billion), based on this model (Gil, 2011). The Hong Kong Tramway (see Figure 6), which has operated since 1904, still maintains its competitiveness today with the least expensive, cleanest and minimal consumption of space among such systems while operating without public subsidies (Transdev, 2014).

Equitably Sustainable Transportation

Equitable sustainability in urban transportation involves ensuring a good, fair distribution of transport services and a justified cost structure across the different segments of society, in order to achieve community cohesion and livability. There is often a divide between drivers and non-drivers deriving in particular from affordability factors, between road users and non-road users (such as residents) with regards to living environment, and between the mobile and the physically challenged with regards to transport modes. There is a general lack of appreciation of issues related to social equity among cities in the Asia-Pacific Region.

Given their Transit-Oriented Development [TOD] policies, Japan and Hong Kong have been more successful in ensuring a high degree of mobility for the different segments of society. Japan has an excellent rail network both within cities and between cities, and there is a high degree of integration between urban development and transportation facilities (Sakaki, 2012). With a large elderly population, Japan has also developed elderly- and disabled-friendly transport policies (Ministry of Land, Infrastructure, Transport and Tourism, 2001) and introduced the Accessible and Usable Transport Law in 2000 (Takamine, 2004) to ensure barrier-free facilities, elevators and escalators, together with guide blocks for the visually impaired. Existing buses are to be replaced by vehicles with low-floors, or without steps.

Hong Kong has a wide range of public transport alternatives, in terms of both modes and fares, designed to meet the different needs of the population. To improve accessibility, Hong Kong has also introduced the integrated planning of rail developments with residential and urban developments such as the LOHAS [Lifestyle Of

Figure 6. Hong Kong tramways in its 110th year, operated with no public subsidy
(Source: photo taken by the author)

Health and Sustainability] Park, Olympian City and Tung Chung. However, one criticism of these transit-oriented developments is that they could spur the gentrification of low-income areas.

Despite years of successful private vehicle restrictions, Singapore has recently begun to experience public concern resulting from dissatisfaction with public transport services, and the high cost of owning and using cars. In an estimate of the typical cost of using alternative transport modes in Singapore, the amortized and operating cost of using a car for all trips is S$1,960 (US$1,567) per month, whereas the expenses incurred if all such trips were made by taxis is S$1,090 (US$872) per month, but if all these trips are made using public transport, the monthly cost falls to just S$98 (US$78) (Kwok, 2014). This would have been acceptable had the public transport service been relatively efficient. However, overall satisfaction with the public transport system in Singapore has declined from 90.3 per cent in 2011 to 88.8 per cent in 2013, largely because of overcrowding and lack of service reliability (Khamid, 2013).

With rapid motorization, China is also experiencing social divisions between the richer car owners and the rest of society. In the last decade, car ownership in Beijing has rapidly increased at an annual rate of 20.5% along with increasing travel demand (Henning et al., 2011). Furthermore, with a 1.7-fold increase in urbanized areas between 1997 and 2004, and an increasingly diversified urban population due to an influx of migrant workers together with changes in urban land use patterns, Beijing is now experiencing tremendous social pressure due to the rising demand for transport. On some city roads, bicycles – which were once the main transport mode – are banned in favor of cars. Some sidewalks and cycle lanes have also been sacrificed to allow more space for automobiles. Such transport policies have created resentment among the working class who view this as an invasion of their space by the rich (Lee & Ng, 2004).

Social equitability is less likely to be determined by urban transportation development alone. The pace of economic growth, the demographic pattern of the population, the political climate and other aspects such as housing, employment opportunities, health care and education, all contribute towards an equitable society. Nevertheless, since transportation as a whole affects all sectors of society, transport policies which do not take into account the impact on the community are likely to become socially unsustainable at some point in time.

The Lessons Learned and the Challenges Ahead in the Field of Sustainable Transportation

While there are some good practices in the field of sustainability, the cities reviewed are still grappling with environmental and equitable sustainability problems with regard to transportation. Developing cities may well learn from the examples here, that it may be more prudent to invest early in public transportation systems duly integrated into land-use plans, in order to ensure a high degree of public accessibility.

There is a need to bridge the gap between intentions and the actual implementation of technology. A lesson can be learned from China's intention of promoting EVs in the country. Although a new round of subsidies was announced by the central government in September 2013, fuelling expectations of the rapid growth of EVs (Jiang, 2014), the impact of EVs in China has not increased significantly, partly because subsidies are not given directly to the consumers. In addition, adequate charging stations have still not been built in the five pilot cities, and this may signal a lack of political will in the implementation process.

Innovative ways to develop and finance transport schemes are needed. Besides considering private-public partnerships as a potential form of transport financing, cities also need to explore lower-cost transportation solutions. Instead of an expanding rail network which may not be sustainable economically, alternative transport systems such as the BRT should be considered. Seoul is a good example of implementing a BRT to relieve the heavy financial burden on government.

Socially sustainable transportation remains a major concern in the Asia-Pacific Region, even though Japan appears to have had some success in building social equitability. In rapidly urbanizing countries such as China, this issue may be given very low priority. To ensure this does not become a critical concern, the minimum a city government needs to do is to provide an efficient, inexpensive public transportation system capable of meeting the needs of all segments of society.

SAFE URBAN TRANSPORTATION

Road safety has become an increasingly serious problem in many Asian countries. It is estimated that the number of deaths from road accidents in Asia is about 700,000 per year (World Health Organization, 2009), accounting for more than half of the world's road fatalities. On the other hand, there are some good practices among several Asia-Pacific countries, notably Japan, Australia and Singapore (International Transport Forum, 2014). Japan saw a decline in accident rates for the 13^{th} consecutive year in 2013, while Singapore experienced a 10.6% reduction in the number of accidents with fatalities or injuries in 2013 compared to 2012, and Australia witnessed a 7.9% decrease in road fatalities in 2013 compared to 2012.

On the other hand, China continues to suffer from poor road safety performance, with 62,387 deaths and 237,421 injuries on the roads in 2011 and the situation has exacerbated by rapid motorization with vehicles per capita growing at an annual rate of 14.5% (Ono et al., 2013).

In general, the concern for safety is linked directly to the overall affluence and economic status of the country. Safety progresses from the encouragement of good individual practices to the development of good community norms. Traditionally this is dealt with via three important approaches: Engineering, Education and Enforcement. This section reviews the status of road safety practices in the Asia-Pacific cities, each at a different stage of maturity in terms of transport safety.

Road Safety Education

With an aging population, Japan is focusing, among other things, on safety training for all elderly road users. Lecture programs and classes have been designed especially for elderly drivers at the time of driver license renewal (International Association of Traffic and Safety Sciences, 2007). Actual assessment of driving ability, as well as a medical examination, is mandatory for drivers aged 70 and above. To ensure safety while encouraging mobility among the elderly, the government has supported the establishment of safety clubs in seniors' clubs and retirement homes, and promoted the training of *Silver Leaders* to champion safety education among the elderly. One of the reasons for the success of this program is that in Japan, safety is considered holistically, whereby all segments of society are taught to be aware of hazards in the workplace, in the home and on the road, and are trained to respond proactively to these hazards at both individual and community levels.

In Australia, the emphasis on road safety is to develop a safety culture as a strategic objective, and this initiative is spearheaded by a high-level council comprising selected political leaders (Australian Transport Council, 2011). To achieve its action plan of "Safe Roads, Safe Speeds, Safe Vehicles and Safe People", the Australian government works with numerous non-governmental organizations and stake holders, such as Road Safety Education Ltd, Royal Automobile Clubs, the Australian Road Safety Foundation and the Road Safety Council, in the belief that road safety is a shared responsibility. Road safety education is introduced to children at an early age, and their parents are also involved. This is supplemented by a number of programs to educate targeted groups, such as young drivers who tend to take more risks – with regard to drunk driving for example – motorcyclists who are more vulnerable, truck drivers who may be subject to fatigue, and others who may be inexperienced or unfamiliar with road conditions. In keeping with the evidence-based approach to facilitating road safety education, considerable data gathering and analysis projects have been undertaken, and numerous reports produced (Petroulias, 2014).

In Singapore, safety education takes the form of regular campaigns, particularly among vulnerable or target groups, e.g. the annual anti-drink drive campaigns are carried out at pubs and during festive seasons (Singapore Traffic Police, 2012), the safe riding campaigns for motorcyclists including two-wheeler delivery personnel and the Shell Games for elementary school children (Singapore Road Safety Council, 2013).

Road Safety Enforcement

In Singapore, regular mandatory vehicle inspections have kept the vehicle population roadworthy, resulting in fewer vehicle breakdowns and mishaps. Heavy goods vehicles and public service vehicles such as taxis and buses are inspected more stringently at 6-monthly intervals (CITA, 2007). As one of the leading car manufacturing countries, Japan has also instituted strict vehicle safety standards in its vehicles, requiring regular inspections to confirm that their structure and equipment comply with safety regulations (Hirota & Minato, 2001). The Japanese authorities have also been updating their regulations to keep pace with technological change (Ministry of Land, Infrastructure, Transport and Tourism, 2013b).

Enforcing safety regulations among road users remains a challenge, particularly in the areas of drunk driving, speeding and red-light violations. Even in Australia, while the absolute numbers of alcohol-related fatalities have continued to decline over the last decade, it is estimated that around 28% of all fatally injured motorists still have a blood alcohol concentration [BAC] above the maximum legal limit of 0.05 (International Transport Forum, 2014). In keeping with international norms, China instituted stricter laws against drunk driving in 2011, which include the possible suspension of a driver's licence for five years and a fine (World Health Organization, 2011). In Taiwan, this problem seems to have been curbed somewhat after several waves of sustained enforcement of heavy fines ranging from TWD 15,000 to 90,000 (US$500 to US$3,000) together with a 1 year ban and a possible prison sentence of up to 2 years. Moreover, if the driver is convicted of causing serious injuries or death, he will be banned from driving for life.

Excessive speed, together with red-light running, contributes directly to a large proportion of serious casualty crashes. Most major cities use fixed and mobile cameras to enforce speed limits; while in Australian cities, Singapore and Hong Kong, red-light cameras have been installed at signalized intersections. International experience (Aeron & Hess, 2009) has shown that red-light cameras may be effective in reducing right-angle crashes but may not be as effective in reducing total crashes due to a possible increase in the number of rear-end crashes. Consequently, it is difficult to identify those sites where such cameras should be installed (Chin & Haque, 2012), although in Australia such enforcement is applicable over an area rather than at a given location.

Road Safety Engineering

Advanced technology in vehicles has also been tested and marketed to improve road safety. Japan has employed the Advanced Cruise-Assist Highway System [AHS], either in a passive or active control mode, to warn drivers of road hazards such as stalled vehicles (Sato, 2003). Such technologies are increasingly being implemented on newer vehicles in order to facilitate driving. In the meantime, a variety of smart systems involving real-time V2I and V2V communications are being developed to facilitate collision avoidance (Ministry of Land, Infrastructure, Transport and Tourism, 2012), including *ITS Spot* which provides safe driving support, adaptive cruise control [ACC] which monitors and controls the gap between vehicles, and cooperative adaptive cruise control [CACC] which effectively connects vehicles in a stream by sharing acceleration/deceleration data (ITS Japan, 2013).

As regards road infrastructure, engineering solutions to improve safety are produced through an audit process. Australia is the regional leader in road safety audits [RSA] which seek to identify and rectify road hazards at the early stages of road design. In 1994, Austroads introduced a safety audit guide which has been the reference procedure for many countries embarking on road safety audits (AustRoads, 2002). Singapore has adopted a similar approach in reviewing the safety of road design for all construction projects that impact changes to the road infrastructure (Land Transport Authority, 2006; Tan et al., 2003). Following a number of pilot RSA studies, China has also developed safety audit manuals, and this practice has been reported in a number of Chinese provinces, such as Guangdong, Xinjiang, Henan, Hebei and Zhejiang (Deng et al., 2012).

Australia has also adopted the *International Road Assessment Program* [iRAP] which was first introduced in Europe to assess rural and inter-city highways, and has further modified the procedure for assessing urban roads. Thus far, the *Australian Road Assessment Program* [AusRAP] has examined more than 20,000 km of national highway with a speed limit of 90 km/hr or above (Australian Automobile Association, 2013). The AusRAP program, which utilizes four complementary methods for assessment – risk mapping, performance tracking, star ratings and safer road investment plans [SRIPs] – is one of the most forward-looking methods of tackling road safety systematically.

One of the major problems in analysing road safety problems is the lack of an integrated crash database shared by highway authorities and hospitals, for analysis and investigation purposes. Australia, Japan and South Korea are participants in the International Road Traffic and Accident Database, maintained by the Federal Highway Research Institute in Germany [BASt] and co-ordinated by the Joint OECD/ECMT Transport Research Committee (International Road Traffic and Accident Database, 2006). In Australia, the Fatal Road Crash Database [FRCD] is managed by the Australian Transport Safety Bureau [ATSB] together with the Victorian Institute of Forensic Medicine [VIFM]. This comprehensive database has allowed Australians to conduct numerous studies into ways of tackling specific road-safety problems (Bureau of Infrastructure, Transport and Regional Economics, 2014). However to date, Japan and South Korea do not seem to have integrated the police and hospital data at their disposal (Luoma & Sivak, 2006). This remains a major challenge in the Asia-Pacific countries.

The Lessons Learned and the Challenges Ahead in the Field of Road Safety

Cities and nations in the Asia-Pacific Region need to adopt a more proactive approach to road safety as practised by the Australians and Japanese. Too often, cities deal with the safety problem only after accidents have accumulated. This is made worse when such accidents have not been accurately recorded or even registered.

The lesson for developing cities is to adopt a top-down approach to safety, focused on establishing a strong institutional structure and a comprehensive safety policy that will translate into safe practices among all road users. For example, the Australians have been successful in developing a safety culture with strong institutional and political support, involving the National Transport Commission, the National Heavy Vehicle Accreditation Scheme, AusRoads and various non-government, and even non-profit, organizations.

Safety Culture usually needs considerable time to develop, especially in developing countries where economic development is more important from a government perspective. All stakeholders must be involved in all aspects of safety promotion. A concerted effort is needed from government, public organisations and commercial companies such as vehicle manufacturers and car parts suppliers, as well as from logistics companies and individuals.

While many safety stakeholder organizations have their own strategic highway safety plans, very often there is no one strategy that unites all of these common efforts. From a government perspective, a national road safety strategy is needed, and can be used as a guide and framework by safety stakeholder organizations, to enhance the planning and implementation of safety measures at national, state and local levels.

Investment in road safety often competes with other priorities. In many cities, there is a lack of funding for safety research and promotion. While funds from the private sector may be tapped into, inevitably public funds need to come to the fore to demonstrate the highest level of commitment to road safety. A good model is the Australian Road Safety Fund which is generated from the fees paid for customised license plates (also known as vanity plates), and is used for a variety of road safety projects. The visibility of such a Fund, and the involvement of various parties in administrating it, probably provides a stronger message on safety promotion than those contained in regular safety campaigns.

CONCLUSION

There are clearly a number of good practices and models of smart, sustainable and safe transportation among the Asia-Pacific cities reviewed here. It may be useful to highlight several important considerations when emulating these practices.

The Need for National Strategies but Local Implementation

First of all, in order to move forward Asia-Pacific countries need to develop national strategies for ITS, transportation sustainability and road safety, if they have not already done so. The vision and strategies need to be formulated at the national level as this will ensure that transportation can be planned with the highest level of commitment and with a long-term view. This will also ensure a good integration of services and the sharing of common applications, e.g. the prepaid fare-card systems, together with a high degree of interoperability across different systems in different cities. Implementation of schemes and action plans may be undertaken at a regional or local level, depending on the needs and readiness of individual cities or municipalities for the change. At the city level, transportation plans may also need to be properly integrated with other initiatives within a smart city design, encompassing energy and water resource management, health care and education. Several implementation problems may arise in relation to the management of project funding and schedules, especially if the projects involve a great number of stakeholders, and if legacy systems need to be replaced.

Do More for Safety and Much More for Sustainability

With regard to national strategies, there seems to be greater readiness among countries to develop national ITS strategies, probably due to the global movement and interest in ITS. Japan is perhaps the best example in the region of a comprehensive national ITS strategy. However, national strategies for urban sustainability and transportation safety are given less emphasis. As regards national road safety strategy, Australia is probably the best example of a nation's commitment to road safety. In order to successfully inculcate a long-term safety culture, it is not enough to focus merely on individual safety programs without working out a national agenda for safety. On the other hand, while there are some good policies and practices in urban sustainable transport, many of these are not well coordinated at the national level. Sustainability is often championed only at local government level. While urban sustainable transportation plans are more easily realized at the local or regional level, it makes greater sense for sustainability goals to be addressed at the national level. This may require certain institutional changes, for example the setting up of a national sustainable transportation agency.

Exploit Technology but also Invest in Know-How

In order for cities to develop smart, sustainable and safe transportation systems, they need to do more than just acquire smart technologies. There is no lack of smart technologies marketed by vendors intent on convincing city officials that the way forward is to procure smart systems. However, the implementation of smart systems needs to be accompanied by the building of capabilities and technical know-how so as to ensure that the systems function effectively, are duly maintained and are upgraded in a timely manner. Not only should the technical system be stress tested, but all non-technical processes should also be rigorously evaluated. The increasing complexity of modern transportation systems, the multiple inter-relationships among stakeholders, and the dynamic changes in technology and user requirements, will make the work of government officials and system implementers even more challenging. Building competencies across all policy and decision makers, and not just among transportation professionals, will be essential in order to ensure transportation systems are intelligently and safely designed and managed, not only for the present generation but also for future generations.

REFERENCES

Aeron-Thomas, A., & Hess, S. (2009). *Red-light cameras for the prevention of road traffic crashes*. Wiley.

Australian Automobile Association. (2013). *Star rating, Australia's national network of highways, Australian Road Assessment Program*. Australia: Australian Automobile Association.

Australian Transport Council. (2011). *National road safety strategy 2011-2020*. Australia: Australian Transport Council.

AustRoads. (2002). *Guide to road safety part 6: Road Safety Audit*. Sydney, Australia: AustRoads.

Bureau of Infrastructure. Transport and Regional Economics. (2014). Road Safety: Modeling a global phenomenon. Canberra, Australia: Bureau of Infrastructure, Transport and Regional Economics.

Chin, H. C., & Haque, M. M. (2012). Effectiveness of red light cameras on the right-angle crash involvement of motorcycles. *Journal of Advanced Transportation*, *46*(1), 54–66. doi:10.1002/atr.145

Chou, J. (2011). *Intelligent transportation systems in Taiwan*. Taiwan: Ministry of Transportation and Communications.

CITA. (2007). *AUTOFORE - Study on the future options for roadworthiness enforcement in the European Union*. Belgium: Comité International De L'inspection Technique Automobile.

Clean Air Initiative for Asian Cities. (2006). *Sustainable urban transport in Asia - making the vision a reality.* Retrieved from http://pdf.wri.org/sustainable_urban_transport_asia.pdf

Cobb, J. (2014). Top 6 plug-in vehicle adopting countries. Retrieved from http://www.hybridcars.com/top-6-plug-in-car-adopting-countries/

Deng, F., Jordan, P., & Goodge, M. (2012). *Reducing traffic accidents in China: strengthening the use of road safety audits. China Transport Topics, 07*. Washington, DC: World Bank.

DieselNet. (2007). *On-road vehicles emission standards in Japan*. Canada: Ecopoint Inc.

Ely, M., & Brick, E. (2012). Bicycle renaissance in a shared way. *Journeys*.

Ezell, S. (2010). *Explaining international IT application leadership: Intelligent transportation systems*. Washington, DC: The Information Technology & Innovation Foundation.

Foo, T. S. (2000). An advanced demand management instrument in urban transport: Electronic road pricing in Singapore. *Cities (London, England)*, *17*(1), 33–45. doi:10.1016/S0264-2751(99)00050-5

Gil, B. (2011). Trends and issues of PPP models in transport focused on South Korea and the UK. In *Proceedings of symposium of Public Private Partnerships in Transport: Trends & Theory, Research Roadmap*. Lisbon, Portugal.

Haque, M. M., Chin, H. C., & Debnath, A. K. (2013). Sustainable, safe, smart - three key elements of Singapore's evolving transport policies. *Transport Policy*, *27*(0), 20–31. doi:10.1016/j.tranpol.2012.11.017

He, H. (2013). *Passenger car fuel-efficiency 2020-2025: comparing stringency and technology feasibility of the Chinese and US standards*. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_PVfe-feasibility_201308.pdf

Henning, T., Mohammed, D. E., & Oh, J. E. (2011). *A framework for urban transport benchmarking*. Retrieved from http://www.utbenchmark.in/img/RefDocuments/Home-Ref-1-3-1.pdf

Highway Industry Development Organization. (2004). *ITS handbook, Japan: 2003-2004*. Japan: Highway Industry Development Organization.

Hirota, K., & Minato, K. (2001). *Inspection and maintenance system in Japan*. In *Proceedings of workshop on Inspection and Maintenance Policy in Asia*. Bangkok, Thailand.

Hocking, D. (2010). *In-vehicle telematics: Informing a National Strategy*.

Hollborn, S. (2002). *Intelligent Transport Systems (ITS) in Japan*. Japan: Institute of Industrial Science, University of Tokyo.

Institute for Transportation & Development Policy. (2013). *Intelligent transportation systems. ADB knowledge Asia case studies project - Seoul*. New York, NY: Institute for Transportation & Development Policy.

International Association of Traffic and Safety Sciences. (2007). *White paper on traffic safety in Japan*. Japan: International Association of Traffic and Safety Sciences.

International Road Traffic and Accident Database. (2006). *BASt site*. Retrieved from http://www.bast.de/EN/Publications/Database/e-itrd/e-itrd-1.html?nn=691198

International Transport Forum. (2014). *IRTAD road safety annual report 2014*. France: International Transport Forum, International Traffic Safety Data and Analysis Group.

Japan, I. T. S. (2013). *ITS green safety showcase*. Tokyo, Japan: ITS Japan. Retrieved from http://www.its-jp.org/english/its-green-safety-showcase/

Japan Automobile Manufacturers Association. (2012). *Japan's domestic shipments of eco-friendly vehicles in fiscal 2011*. Japan: Japan Automobile Manufacturers Association.

Jeon, C. M., & Amekudzi, A. (2005). Addressing sustainability in transportation systems: Definitions, Indicators, and Metrics. *Journal of Infrastructure Systems*, *31*(50).

Jiang, X. (2014). New-energy vehicles 'turning the corner': *ChinaDaily,* 1 July 2014.

Kajiwara, A. (2012). Overview of FY2020 fuel efficiency standards for passenger vehicles. Environmental Policy Division, Road Transport Bureau, Ministry of Land, Infrastructure, Transport and Tourism.

Kang, K., & Kim, I. (2001). Effective policy of ITS for Seoul Korea. In *Proceedings of the Eastern Asia Society for Transportation Studies*.

Kato, K. (2002). *Development of ITS in Japan - Focusing on DSRC*. In *Proceedings of 10th World Congress on ITS*. Madrid, Spain.

Khamid, H. M. A. (2013). Singaporeans' satisfaction with public transport drops. Singapore: Channel News Asia, 12 March 2013.

Korea Advanced Institute of Science & Technology. (2013). *Concept of online electric vehicle project*. Korea: KAIST. Retrieved from http://olev.kaist.ac.kr/en/olevco/1.php

Korea Expressway Corporation. (2009). *ETMS (Expressway Traffic Management System)*. Retrieved from http://www.ex.co.kr/english/business/EX_opp/its/its.jsp

Kwok, J. (2014, June). Car, taxi and bus - how the costs stack up. Singapore. *Sunday Times*, 29.

Land Transport Authority. (2006). *Project safety review (safe-to-build) process*. Singapore: Land Transport Authority.

Lee, J. (2012). *Economic growth and transport models in Korea* (pp. 260–285). Korea: Korea Transport Institute.

Lee, J., Kim, D., Kwon, Y., & Ha, S. (2012). *A comparison study on two bike sharing programs in Korea*. In *Proceedings of Annual Meeting Transportation Research Board*.

Lee, S., & Ng, W.-S. (2004). Rapid motorization in China: Environmental and social challenges. *ADB-JBIC-World Bank East Asia and Pacific Infrastructure Flagship Study*.

Leong, J. (2014). Singapore-Taiwan cross-border contactless card in the works. Retrieved from http://www.channelnewsasia.com/news/singapore/singapore-taiwan-cross/1132598.html

Levinson, H., Zimmerman, S., Clinger, J., Gast, J., Rutherford, S., & Bruhn, E. (2003). Bus Rapid Transit: Vol. 2. *Implementation Guidelines*. Washington, DC: Transportation Research Board, National Academies.

Lew, Y.D., & Ang, C.I. (2010). The LTA Journey: 15 Years. *JOURNEYS.*

Local Governments for Sustainability. (2011). *Hangzhou, China, the world's largest bike sharing program*. Retrieved from http://www.ecomobility.org/fileadmin/template/project_templates/ecomobility/files/Publications/Case_stories_EcoMobility_Hangzhau_PDF_print.pdf

Luoma, J., & Sivak, M. (2006). *Characteristics and availability of fatal road-crash databases worldwide*. Transportation Research Institute, University of Michigan.

Ministry of Environment. (2008). *A protocol target achievement plan (revision)*. Japan: Ministry of Environment.

Ministry of Finance. (2013). *Factsheet on Singapore air quality. Budget Singapore 2013*. Singapore: Ministry of Finance.

Ministry of Land. Infrastructure, Transport and Tourism. (2001). *White paper on land, infrastructure and transport in Japan*. Japan: Ministry of Land, Infrastructure and Transport.

Ministry of Land. Infrastructure, Transport and Tourism. (2009). Efforts for environmentally sustainable transport in Japan. Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Ministry of Land. Infrastructure, Transport and Tourism. (2012). ITS initiatives in Japan. Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Ministry of Land. Infrastructure, Transport and Tourism. (2013a). The micro mobility and future development. Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Ministry of Land. Infrastructure, Transport and Tourism. (2013b). Partial amendments of the "Safety Regulations for Road Transport Vehicle", and the "Public Notice that prescribes Details of Safety Regulations for Road Transport Vehicle". Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Motavalli, J. (2010). China to subsidize electric cars and hybrids, *The New York Times*.

National Transport Commision. (2011). *National In-vehicle telematics strategy*. Australia: The Road Freight Sector, National Transport Commission.

National Transport Information Center. (2014). *Introduction to intelligent transport systems. Republic of South Korea*. National Transport Information Center.

Ono, Y., Silcock, D., & Gloria, G.-T. (2013). International lessons for road safety in the People's Republic of China. *ADB East Asia Working Paper Series.*

Organisation for Economic Co-operation and Development. (2013). *Funding urban public transport, case study compendium*. Paris, France: Organisation for Economic Co-operation and Development.

Ou, H. (2013). Beijing ETC system to be linked to Shangdong, Shanxi, *China Daily*.

Pan, H. (2011). *Implementing sustainable urban travel policies in China*. In *Proceedings of International Transport Forum*. Leipzig, Germany.

Peng, Z. R., & Lu, Q. C. (2012). *China's public transportation: problems, policies, and prospective of sustainability*. ITE Journal.

Petroulias, T. (2014). *Community attitudes to road safety – 2013 survey report*. Melbourne, Australia: Social Research Centre.

PRTM. (2011). *The China new energy vehicles program - challenges and opportunities*. Geneva, Switzerland: The World Bank.

Pucher, J., Park, H., Kim, M. H., & Song, J. (2005). Public transport reforms in Seoul: Innovations motivated by funding crisis. *Journal of Public Transportation*, *8*(5), 41–62. doi:10.5038/2375-0901.8.5.3

PwC. (2013). *The Singapore land transport master plan 2013 - A review by PwC*. Singapore: PricewaterhouseCoopers.

Sakaki, S. (2012). *TOD in Japan: Experiences and lessons*. Paper presented at second annual meet of the Sustainable Urban Transport Project.

Santos, G., Wai, W. L., & Koh, W. T. H. (2004). Transport policies in Singapore. *Research in Transportation Economics*, *9*, 209–235. doi:10.1016/S0739-8859(04)09009-2

Sato, N. (2003). Advanced Cruise-Assist Highway Systems. *ITS handbook 2002-2003*.

Singapore Road Safety Council. (2013). *Towards safer roads in Singapore*.

Singapore Traffic Police. (2012). *STCars anti drink drive campaign 2012*. Singapore: Singapore Traffic Police.

Taipei City Government. (2010). *Taipei yearbook 2009*. Taipei: Taipei City Government.

Takamine, Y. (2004). *Infrastructure services and social inclusion of persons with disabilities and older persons in East Asia and the Pacific*.

Tan, J. K., Stolz, D. R., & Mijan, S. (2003). *Safe to build and safe to use – a total safety management system*. Paper presented at Rail Transit System Conference, Singapore.

Tan, Z. (2012). New transport plan driven by technology. *China Daily*.

Toyota (2014). Toyota's philosophy for a safe vehicle. *Safety Technology*. Japan: Toyota Technology File.

Transdev (2014). The Hong Kong Tramway, operated since April 2009 by the Transdev RATPDev joint venture, Hong Kong Tramways, is celebrating its 110th anniversary. *Transdev*. Retrieved from http://www.transdev.com/en/media/press-releases/1166.htm

TransportPolicy.net. (2013). *South Korea: light-duty: emissions*. Retrieved from http://transportpolicy.net/index.php?title=South_Korea:_Light-duty:_Emissions

Tyco Traffic & Transportation. (2014). *SCATS, urban traffic control*. Australia: Tyco Traffic & Transportation.

World Health Organization. (2009). *Global status report on road safety: time for action*. Geneva, Switzerland: World Health Organization.

World Health Organization. (2011). *Road safety in China*. Geneva, Switzerland: World Health Organization.

Wu, J., Sui, Y., & Wang, T. (2009). Intelligent transport systems in China. In *Proceedings of the ICE - Municipal Engineer.*

ADDITIONAL READING

Akiyama, T., Kamata, M., Wahira, Y., & Fujii, N. (2001). Vehicle accessibility in Japan today and the outlook for the future. *IATSS RESEARCH*, *25*(1), 42–50. doi:10.1016/S0386-1112(14)60005-4

Australian Conservation Foundation. (2013). Investing in sustainable transport: Our clean, green transport future. Australia: Australian Conservation Foundation and Rapid, Active and Affordable Transport Alliance (RAATA).

Barter, P. A. (2011). *Parking Policy in Asian Cities*. Manila, Indonesia: Asian Development Bank.

Calimente, J. (2012). Rail integrated communities in Tokyo. *Journal of Transport and Land Use*, *5*(1), 19–32. doi:10.5198/jtlu.v5i1.280

Changwon Public Health Center. (2010). *Environmentally sustainable & healthy urban transportation – towards public bike rental system*.

Chin, H. C. (1998). Urban transport planning in Singapore. In B. Yuen (Ed.), *Planning Singapore: From Plan to Implementation*. Singapore: Singapore Institute of Planners.

Chin, H.C. (2011). Sustainable urban mobility in South-Eastern Asia and the Pacific. *Global Report on Human Settlements 2013*.

Chin, H. C., Yuen, B., Debnath, A. K., & Haque, M. M. (2011). Benchmarking smart and safe cities. Research report funded by the Ministry of Education Academic Research Fund Tier 1 Grant. Singapore.

Debnath, A. K., Chin, H. C., Haque, M. M., & Yuen, B. (2014). A methodological framework for benchmarking smart transport cities. *Cities (London, England)*, *37*(0), 47–56. doi:10.1016/j.cities.2013.11.004

Debnath, A. K., Haque, M. M., Chin, H. C., & Yuen, B. (2011). Sustainable urban transport: Smart technology initiatives in Singapore. *Transportation Research Record*, *2243*(-1), 38–45. doi:10.3141/2243-05

Dirks, S., & Keeling, M. (2009). *A vision of smarter cities, how cities can lead the way into prosperous and sustainable future*. Somers, NY: IBM Institute for Business Value.

European Union. (2011). *Intelligent transport systems in action.* Bruxelles, Belgium: European Union.

Han, S. S. (2010). Managing motorization in sustainable transport planning: The Singapore experience. *Journal of Transport Geography*, *18*(2), 314–321. doi:10.1016/j.jtrangeo.2009.06.010

Haque, M. M., Debnath, A. K., & Chin, H. C. (2010). *Sustainable, smart, safe: a 3 'S' approach towards a modern transportation system*. In *Proceedings of International Conference on Sustainable Built Environment*. Kandy, Sri Lanka.

Hirasawa, M., Asano, M., & Saito, K. (2005). Study on designing and introduction of a road safety management system as a new road safety policy. [). Bangkok, Thailand.]. *Proceedings of the Eastern Asia Society of Transportation Studies*, *5*, 2018–2031.

Houghton, J., Reiners, J., & Lim, C. (2009). *Intelligent transport, how cities can improve mobility*. Somers, NY: IBM Institute for Business Value.

Hoye, J., Andreadakis, I., & Vercoe, S. (2011). *National Transport Commission, smart transport for a growing nation: Public attitudes to mobility and access, social research report*. Australia: GA Research.

IBM. (2013). *IBM's smarter cities challenge, Kyoto report*. Armonk, NY: IBM Corporate Citizenship & Corporate Affairs.

Ibrahim, M. F. (2003). Improvements and integration of a public transport system: The case of Singapore. *Cities (London, England)*, *20*(3), 205–216. doi:10.1016/S0264-2751(03)00014-3

International Transport Forum. (2013). *IRTAD road safety annual report 2013*. France: International Transport Forum, International Traffic Safety Data and Analysis Group.

Kodukula, S. (2011). *Reviving the soul in Seoul: Seoul's experience in demolishing road infrastructure and improving public transport*.

Lim, S. H. (2012). Intelligent transport systems in Korea. *International Journal of Engineering and Industries*, *3*(4), 58–64.

Matthew, L.J. (2013). *Vehicle fuel efficiency standards*. Commonwealth of Australia: Department of Parliamentary Services, Parliament of Australia.

Metcalfe, J., & Smith, G. (2005). *The Australian Road Assessment Program (AusRAP)*. Paper presented at Australian Road Safety Research Policing Education Conference, Australia.

Morgan, R. (2005). Road Safety Audits – Practice in Australia and New Zealand. *ITE Journal*, 22-25.

National Transport Commission. (2011). *Electronic systems for heavy vehicle driver fatigue and speed compliance – Policy paper*. Melbourne, Australia: National Transport Commission.

National Transport Commission. (2013). *Cooperative Intelligent Transport Systems - final policy paper*. Melbourne, Australia: National Transport Commission.

New Jersey Department of Transportation & Pennsylvania Department of Transportation. (2008). *Smart Transportation Guidebook: Planning and designing highways and streets that support sustainable and livable communities. US: New Jersey Department of Transportation*. Pennsylvania: Department of Transportation.

Njord, J., Joseph, P., Freitas, M., Warner, B., Allred, K. C., Bertini, R., & Warne, T. et al. (2006). *Safety Applications of Intelligent Transportation Systems in Europe and Japan. International Technology Scanning Program*. US: U.S. Department of Transportation.

Ranaiefar, F. (2012). *Intelligent freight transportation systems*. Institute of Transportation Studies.

Roads and Traffic Authority of New South Wales. (2011). *Guidelines for Road Safety Audit Practices*. Transport Roads & Traffic Authority.

Talukdar, M. H. (2013). Transport pricing policy in Hong Kong. *Management Research and Practice*, *5*(2), 22–30.

Tourism & Transport Forum. (2011). *Tax incentives for sustainable transport*. Australia: Tourism & Transport Forum.

UN-HABITAT. (2013). *Planning and design for sustainable urban mobility: Global report on human settlements 2013*. Oxon: Routledge.

Watanabe, R. (2005, March). *Overview of the public transport system and policy in Japan*. Paper presented at the Workshop on Implementing Sustainable Urban Travel Policies in Japan and other Asia-Pacific countries. Tokyo, Japan.

KEY TERMS AND DEFINITIONS

Adaptive Cruise Control [ACC]: A radar-based system that can continually adjust a vehicle's speed to maintain a safe distance from the vehicle ahead.

Bus Rapid Transit [BRT]: A bus-based mass transit system, with buses running for most part of their journey within a fully dedicated right of way, often having priority over other vehicles at traffic intersections.

Certificate of Entitlement [COE]: The system practiced in Singapore to regulate growth in the vehicle population by limiting the ownership of individual vehicles to a maximum lease of 10 years through a process of bidding.

Dedicated Short Range Communication [DSRC]: A short-range to medium-range communication service with very high data transfer rates, that is designed for automotive use to support vehicle-to-infrastructure and vehicle-to-vehicle operations.

Electronic Toll Collection [ETC]: A system that collects road tolls electronically often without the need for vehicles to stop.

Intelligent Transport Systems [ITS]: Advanced info-communication applications designed to provide innovative features in the different transport modes, to enable users to be better informed for the smarter, safer and more coordinated use of transport services.

Micro-Electric Vehicle [MEV]: A one- or two-seater vehicle powered by battery with an electric propulsion power rating of 4-10 KWh.

On-Board Units [OBU]: The computer unit installed within a vehicle that collects driving and traffic information and can communicate with roadside and satellite control or guidance systems, usually for the purpose of toll collection, and having the potential to communicate with other vehicles' OBUs.

Road Safety Audit: A formal examination of the safety performance of an existing or future road scheme or intersection design by an independent team, that aims at identifying potential road hazards and recommending mitigating measures designed to improve the safety of all road users.

Sag-Congestion: Congestion resulting from vehicles having to reduce speed when they are at the bottom of a slope just prior to climbing uphill.

Smart City: A holistic urban system, involving components such as transportation, healthcare, utilities, education, housing, public safety and security, communications and businesses, that integrates sensors and actuators in the infrastructure to operate an integrated, self-sustaining management system through the intelligent use of information and communications networks.

Sustainable Transportation: A set of transportation policies, schemes or activities that collectively ensure that the burden or costs of implementing or operating them will not be passed on to future generations.

Transit-Oriented Development [TOD]: A residential and commercial district built around a public transport station or interchange, in order to maximize access and to encourage public transport usage.

Variable Message Sign [VMS]: An electronic traffic sign installed on roadways to provide drivers with information about traffic conditions on the road or at car parks, such as congestion, accidents, speed limit changes and parking availability.

Vehicle-to-Infrastructure [V2I]: The wireless technology that facilitates the exchange of operational data between vehicles and highway infrastructure, primarily to better manage traffic movements and promote safer operations, and to automate road toll collection.

Vehicle-to-Vehicle [V2V]: An automobile-based technology designed to allow automobiles to "talk" to each other for efficient exchanges of vehicle-based data regarding location and speed, thereby allowing a faster response to traffic hazards.

Chapter 13
Wireless Access Networks for Smart Cities

Hervé Rivano
Inria, France

Khaled Boussetta
Université Paris 13, France & Inria, France

Isabelle Augé-Blum
INSA Lyon, France& Inria, France

Marco Fiore
CNR, Italy & Inria, France

Walid Bechkit
INSA Lyon, France & Inria, France

Razvan Stanica
INSA Lyon, France & Inria, France

Fabrice Valois
INSA Lyon, France & Inria, France

ABSTRACT

Smart cities are envisioned to enable a vast amount of services in urban environments, so as to improve mobility, health, resource management, and, generally speaking, citizens' quality of life. Most of these services rely on pervasive, seamless and real-time access to information by users on the move, as well as on continuous exchanges of data among millions of devices deployed throughout the urban surface. It is thus clear that communication networks will be the key to enabling smart city solutions, by providing their core support infrastructure. In particular, wireless technologies will represent the main tool leveraged by such an infrastructure, as they allow device mobility and do not have the deployment constraints of wired architectures. In this Chapter, we present different wireless access networks intended to empower future smart cities, and discuss their features, complementarity and interoperability.

INTRODUCTION

Since 2009, more than half of the world's population now lives in urban areas, a proportion that exceeds 75% in developed countries and will grow to 60% worldwide by 2030 (United Nations, 2012). The rapid rise of cities yields new societal challenges with strong scientific and technological implications. As the population density starts to exceed 5.000 inhabitants per km^2, all type of living resources face a dramatic growth in demand. This applies to natural goods, such as water or gas, as well as to infrastructures, such as transportation systems, energy grids and telecommunication

DOI: 10.4018/978-1-4666-8282-5.ch013

networks. The problem is the availability of such resources will not increase at the same rate as their demand, as testified by recent forecasts on sustainable development (United Nations, 2013), on road capacity and energy distribution (International Energy Agency, 2012), and on global mobile data traffic (Cisco, 2013).

The answer to the needs of mass urbanization lies then in the way the resources at our disposal are managed, and Information and Communication Technologies (ICT) are expected to play a key role in that process. The complete list of use cases for ICT in future smart cities is vast and varied, with a large number of applications that promise to have a significant impact on the efficient management of urban resources in just a few years from now. In fact, most such applications strongly rely on communication. The mobility and pervasiveness of the devices participating in the process commend that data transfers – at least those including end users – are mainly wireless. However, the nature of network access (by hundreds of thousands of autonomous or mobile devices) and the type of traffic generated (from small-size periodic data to high-definition video streaming) define new usages over large (i.e. metropolitan) scales, which cannot be accommodated solely via the traditional communication infrastructure. This makes the case for original networking solutions that can efficiently cope with the future communication demands of smart cities. On the one hand, there is the necessity to enhance the existing cellular infrastructure, especially in terms of radio access. Although connection speeds are expected to augment 7-fold by 2017 (due partly to the additional capacity provided by heterogeneous deployments, as well as to traffic offloading via femtocells and Wi-Fi), this will not suffice to manage the overall 13-fold increase in mobile data traffic by the same date (Cisco, 2013). On the other hand, short-range wireless technologies, such as Wi-Fi, DSRC, and Zigbee will empower ubiquitous meshed architectures, based on the M2M paradigm and specifically designed to manage the load offered by smart city services.

As a result, there is a clear need for innovative communication network models in the wireless last mile, i.e. that bridging end terminals – be they autonomous devices or mobile appliances under the control of users – to the wired network. In fact, the network paradigms envisioned to enable smart cities are not far from those studied by the research community over the last decade. One can find glimpses of the vision that accompanied studies on wireless sensor networks, mesh networks, vehicular networks, and ad hoc networks in general. However, there is more to smart city communication infrastructure than the direct implementation of state-of-the-art protocols proposed for the aforementioned wireless networks.

In this Chapter, we present wireless last-mile communication technologies for upcoming smart cities. The *"Background"* section presents the technologies that are currently employed to provide wireless access to users and devices. Such technologies, falling into the two wide categories of cellular and wireless local-area networks, have been dominating the market for over a decade: the presentation of their architecture and major features represents the natural starting point for our treatise. The *"Emerging wireless access technologies"* section presents a wide range of diverse solutions that are gaining momentum nowadays in the context of ICT for urban environments. Our discussion includes both direct evolutions of the cellular and wireless local area network paradigms as well as innovative and disruptive solutions, based on communication to, from and among sensors, vehicles and mobile terminals. The section provides a comprehensive overview of the underlying technologies that may contribute to the overall ICT architecture in upcoming smart cities. The *"Future research directions"* section outlines how the different technologies presented before – each dedicated to a specific need in terms of the smart city wireless communication infrastructure, and typically regarded in isolation – need ultimately to coexist. We thus introduce a unifying paradigm for wireless technologies in smart cities, under the term of *capillary networking*. We discuss future research challenges arising from such a holistic viewpoint on emerging wireless access. The *"Conclusion"* section closes the Chapter, summarizing the main points emerging from the discussion.

BACKGROUND

Wireless access infrastructures are currently based on two complementary network paradigms, i.e. cellular and local-area architectures. In order to better understand their evolution within the smart city context, below we provide a brief overview of the technologies they build upon.

Cellular Network Infrastructure and Technologies

Cellular networks are based on architectures operated by telecommunications companies. They are designed to provide telephony services, such as voice calls, fax and Short Messages Services (SMS), as well as data traffic services to *mobile* users, with a *pervasive* coverage. Support of mobility is enabled by the use of wireless technologies that allow users to freely travel (possibly over large distances and at high speed) while carrying and using their communication devices. Pervasive coverage means instead that a user is able to receive or initiate a cellular phone call or data session from any place. Cellular networks are intended to provide different Quality of Service (QoS) levels to users, in return for an access fee charged by the operator.

In order to allow complete user mobility, the communication occurs between a user-carried mobile terminal and a so-called fixed base station – both equipped with radio transmitter(s) and receiver(s), and capable of emitting and receiving radio-frequency signals. The communication occurs over reserved portions of the electromagnetic spectrum, and exchanges are bidirectional, as the radio signal carrying the information can be emitted by the mobile user's terminal and received by the base station (uplink direction), or be emitted by the base station and received by the terminal (downlink direction). Each communication occupies one specific portion of such a spectrum, also referred to as a *channel*.

The physical properties of radio-frequency signal propagation result in a significant attenuation of the same with the distance between the transmitter and the receiver. Theoretically, the attenuation is at least proportional to the square of the distance, but it is often much greater due to the environment in which the base station and the mobile terminal are located. Indeed, the presence of static and mobile obstacles around and between the transmitter and receiver causes reflections, refraction, diffraction, Doppler and multipath effects. In turn, these lead to a finite maximum distance between the transmitter and receiver. As a consequence, each base station can serve users within a limited geographical area, named *cell*. Pervasive coverage is then guaranteed by deploying base stations so that the superposition of the corresponding cells covers the whole target territory.

The tessellation of space into cells allows different base stations to use the same channels to serve different users. This operation must however be performed with care, since radio-frequency signal propagation cannot be precisely controlled and thus typically trespasses the cell boundaries. This implies that simultaneous transmissions occurring within nearby cells and over the same channels risk interfering with each other and disrupting both communications. The way channels are allocated within the spectrum and the mechanisms used to manage this so-called co-channel interference are the main differences between the different technologies that have characterized subsequent generations of cellular networks. Below, we introduce the features of the second- and third-generation architectures that are dominant in today's deployments.

Second Generation Cellular Networks: GSM, GPRS and EDGE

The second generation of cellular networks (often referred to as 2G) maps to GSM (Global System for Mobile Communications), whose share exceeds 90% of the total 2G market. GSM only supports mobile telephony services, and defines channels as time-frequency slots, and thus adopts mixed Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) techniques to make multiple base station-to-user communications co-exist within the available spectrum.

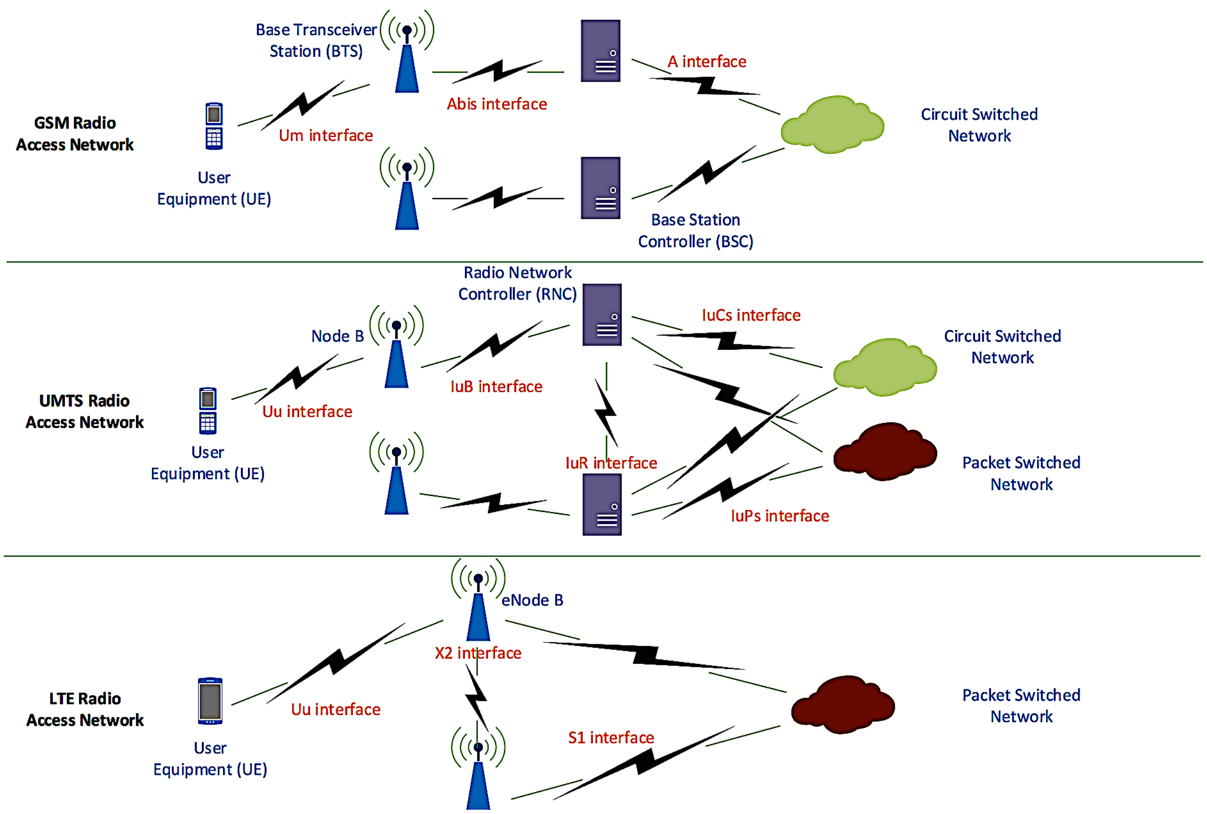
More precisely, the GSM standard defines several carrier frequency ranges in the ISM band. Most current deployments use the 850-900 MHz band, and some include the 1800-1900 MHz band. The GSM band is then divided into two sub-bands, dedicated to uplink and downlink communication respectively. To carry a phone call, the system has to allocate one GSM downlink channel and one GSM uplink channel, which are released once the call is terminated.

Different cells can use the same GSM channels. However, in order to avoid co-channel interference, channel reuse – which in fact translates into frequency channel reuse in GSM – is not allowed among cells that are too close to one another. Specifically, the larger the distance between cells reusing the same frequencies, the lower the interference (and the better the QoS); however, larger distances among these cells also mean that the same channels can be used fewer times throughout the network, which negatively affects the capacity to accommodate user demand. The planning of frequency allocation in GSM networks is thus quite a complex task, aiming at maximizing frequency reuse while maintaining co-channel interference below a minimum threshold.

A typical GSM infrastructure, shown in the top plot of *Figure 1*, relies on a set of Base Transmitter Stations (BTS) that are connected through wired Pulse-Code Modulation (PCM) lines to a set of switches called Base Station Controllers (BSC). BSC are responsible for timeslot allocation for voice traffic, managing the handover of users between adjacent cells and radio resource monitoring. BSC are connected to the core GSM network, which is composed of a set of gateways and databases that provide several functions in addition to managing radio interface e.g. interconnecting with the public switched telephone network, identifying and locating mobile subscribers, routing calls, billing and securing communications).

The GSM infrastructure was designed by telecommunication actors following the telephony circuit switched model in order to ensure interconnection with public switched telephone networks. However, the rapid development of Internet and its tremendous popularity among users in the 1990s led standardization bodies – namely ETSI – to extend the GSM standard in order to support data traffic. The first extension to meet with some success was GPRS (General Packet Radio Service). GPRS introduces several upgrades at the radio interface and in the core infrastructure. To ensure retro-compatibility with previous GSM versions, as well as interoperability with the emerging Internet, GPRS extends the core network with new components to enable packet switching. In particular, gateways (called GGSN and SGSN) are added within the core network to allow external Internet connectivity. Also, a Packet Control Unit (PCU) is added to the BSC. The PCU is responsible for allocating GSM channels to data traffic in a dynamic fashion, i.e. only when there are data bursts. Moreover, the PCU

Figure 1. Cellular network architectures in GSM (top), UMTS (middle) and LTE (bottom)



implements a scheduling mechanism that is used to share available channels among concurrent data sessions. A later GPRS upgrade consisted of introducing Coding Schemes (CS) at the radio interface in order to increase the bit rate according to the signal quality, by transmitting bursts with a certain redundancy rate.

Despite these enhancements, the maximum GPRS bit rate was, in the late 1990s, at least one order of magnitude lower than that promised by emerging wireless local area network technologies such as Wi-Fi. To reduce this gap, ETSI proposed an updated version of GPRS, named Enhanced Data Rates for GSM Evolution (EDGE). This standard introduced limited modifications to the GPRS infrastructure. The main innovation is the support of adaptive modulation schemes at the radio interface: by adapting the number of modulated carriers, a transmitter can adjust its bit rate depending on the quality of the signal. EDGE defines up to eight combinations of modulation and coding schemes, with bit rate per time-slots ranging from 8.8 to 59.2 Kbit/s, and a maximum bit rate per downlink connection up to 384 Kbit/s.

Third Generation Cellular Networks: UMTS and HSDPA

EDGE/GPRS standards were also denoted as 2.5G technologies, a prelude of the actual third generation, or 3G technologies. The latter were embodied by UMTS (Universal Mobile Telecommunications System), which was standardized by 3GPP in the early 2000s.

UMTS introduced major modifications to cellular architectures. Firstly, the radio interface was substantially modified, moving from a TDMA/FDMA scheme to a WCDMA (Wideband Code

Division Multiple Access) scheme, as detailed by Holma and Toskala (2001) in a dedicated book. WCDMA is based on Direct Sequence Spread Spectrum (DSSS), a spread spectrum technique that encodes each data bit with a chip sequence – or code. This operation spreads the bits over the available spectrum, with the result that the transmitted signal occupies a much larger bandwidth than the original bandwidth of the data signal. However, it also allows multiple transmissions to simultaneously use the same frequency bandwidth by using orthogonal codes. The result is a range of advantages over FDMA/TDMA, including higher spectrum efficiency, reduced power transmission levels and greater robustness to multipath effects and inter-symbol interference. DSSS also makes it possible to relax the orthogonal code constraint (and thus to accommodate more codes within the same spectrum, increasing the system capacity) at the expense of some interference.

From a networking viewpoint, although most of the GSM entities were maintained in UMTS (possibly with a new terminology, see the middle plot in *Figure 1*), the associated protocols were updated so as to complete the switch from a circuit switched to a native packet switched architecture. Several interfaces and protocols, such as ATM or IP, were introduced in the UMTS core network protocol stack to replace circuit switched lines.

The increase in access capacity (with up to 2 Mbit/s transfers in the first release of UMTS) and the evolution of the core network toward a packets switched architecture deeply modified the utilization of cellular networks and enlarged the number of offered services. Since the introduction of UMTS, cellular data traffic has seen a continuous increase, especially with the success of smartphones and mobile applications. Accommodating such an increasing demand has required the 3GPP to release several enhancements of UMTS, which led to so-called 3.5G standards. Among these releases, High Speed Downlink Packet Access (HSDPA) has been widely deployed by cellular operators. Similarly to the evolution from 2G to 2.5G, the HSDPA technology did not introduce any major modifications to the network infrastructure. Most of the upgrades were instead at the radio interface and eNodeBs (i.e. the equivalent of BTS in GSM). In particular, HSDPA moved some functions, such as radio resources allocation, from the core network to the eNodeB, with the aim of improving the system's responsiveness to the fast-changing radio channel conditions. Moreover, new and denser coding schemes, including 16QAM, were added, enabling a maximum downlink bit rate of 14.4 Mbit/s.

Wireless Local Area Network Infrastructure and Technologies

With the rapid acceleration of the computer industry, and with the introduction of personal computers, the 1980s also saw an increased demand for interconnection and communication capabilities. At that point, Local Area Networks (LAN) were already a reality, implemented via wired technologies such as Ethernet. However, wireless networks, with their ease of deployment and reduced material cost, were also becoming technically feasible.

Encouraged by a decision made by the US Federal Communications Commission, which in 1985 allowed the unlicensed use of 100 MHz of spectrum in the 2.4 GHz band (one of the so-called Industrial, Scientific and Medical (ISM) radio bands), equipment manufacturers began proposing their solutions for wireless local area networks (WLAN), mostly operating in this ISM band. However, inter-connection problems soon emerged, and different standardization organizations decided to address the issue. In 1997, the Institute of Electrical and Electronics Engineers (IEEE), which had already standardized an Ethernet-like solution for wired networks, published the IEEE 802.11 standard, specifying the Medium Access Control (MAC) and Physical (PHY) layers of wireless LANs.

Easy to implement and quickly brought to the market by manufacturers supporting the standard, IEEE 802.11 soon emerged over competing technologies and became the de-facto standard for WLANs. However, early IEEE 802.11 products still had inter-operability problems, mostly because different manufacturers were giving different interpretations of some parts of the standard. As IEEE lacked the resources needed to test equipment compliance, companies supporting the IEEE 802.11 standard created an independent organization, the Wi-Fi alliance, to test and certify IEEE 802.11 products. This also led to the commercial name of Wi-Fi, generally used today to designate certified IEEE 802.11 equipment.

The specifications are being continuously adapted to the dynamic wireless market, allowing Wi-Fi to operate today on different frequency bands, from the 700 MHz band freed by the switch from analog to digital television broadcast, to the 60 GHz ultra-wide band, which allows a significant increase in transmission data rate. Most Wi-Fi WLANs operate however at 2.4 and 5 GHz (the latter band being first used by amendment IEEE 802.11a), where 3 to 12 non-overlapping 20-MHz frequency channels are available. The standard was also adapted to a number of specific environments, such as mesh networks, vehicular communications, or direct device-to-device transmissions. These functions are added to the standard through so-called *amendments*, discussed and drafted by different working groups within IEEE.

At the physical layer, the standard initially used spread spectrum techniques, such as Direct Sequence Spread Spectrum (DSSS in the original standard) or Frequency Hopping Spread Spectrum (FHSS in the IEEE 802.11b amendment). However, Orthogonal Frequency Division Multiplexing (OFDM), introduced by amendments IEEE 802.11a/g, has become the prevalent choice in the last decade, and all recent devices use this technique, sometimes with complementary mechanisms, such as transmission and reception through multiple antennae.

The IEEE 802.11 standard describes two MAC layer protocols, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The latter is a deterministic channel access method, where a central master station (STA), typically the Wi-Fi Access Point (AP), polls all the regular STAs, granting them transmission opportunities. On the other hand, DCF is a contention-based method, using Carrier Sense Multiple Access (CSMA), whose main principle is that every STA listens to the channel before attempting a transmission and refrains from doing so if another station is already using the channel. DCF uses acknowledgement (ACK) messages to detect failed transmissions, and takes a binary back-off approach to reduce the collision probability between STAs, implementing a Collision Avoidance (CA) mechanism – hence the name CSMA/CA, generally used to describe this medium access solution.

Although described in the standard, and despite the greater quality of guaranteeing finite channel access time, PCF is not typically implemented in off-the-shelf Wi-Fi devices, which only run DCF and its evolutions. One of these evolutions, Evolved Distributed Channel Access (EDCA), has been defined in the IEEE 802.11e amendment, and later included in the recent IEEE 802.11-2012 standard (IEEE Computer Society, 2012). It proposes the use of transmission queues with different priorities, making it possible to distinguish between data traffic with real-time constraints and classical *best effort* data at the MAC sub-layer.

Building on these continuous improvements and the development of wireless communications, in less than a decade Wi-Fi has become the most successful wireless technology worldwide. According to the Cisco Data Meter application (CDM, 2014), Wi-Fi is the main wireless technology used to access Internet services, transporting three to four times more data than cellular networks. While this difference is more significant in the case of tablets, as depicted in *Figure 2*, it is interesting to notice that even in the case of smartphones Wi-Fi largely dominates as an access technology, as shown in *Figure 3*.

EMERGING WIRELESS ACCESS TECHNOLOGIES

Second- and third-generation cellular and Wi-Fi access networks are designed to accommodate a type of mobile traffic that is rapidly becoming outdated.

On the one hand, we are witnessing a growth in data traffic demand from mobile users which was barely predictable only a few years ago. The success of smartphones and mobile apps led to a mobile traffic compound annual growth rate (CAGR) of 146% between 2006 and 2013 – a performance surpassing even that of the overall data traffic over the turn of the millennium, i.e. when the Internet first started to pervade our lives. This notwithstanding, forecasts by prominent stakeholders tell us that the mobile communication hype is far from having reached its peak: mobile data traffic is still expected to grow 11-fold by 2018, with a CAGR of 61% (Cisco, 2013). This makes the data rates offered by the 2G/3G cellular network and 802.11a/b/g Wi-Fi networks insufficient. Therefore, both access technologies are being improved in order to meet the increased demand, which promises to be especially challenging in ever-more-densely populated urban environments.

On the other hand, smart cities are expected to introduce a number of services that rely heavily on wireless access, but introduce traffic demands of an unprecedented nature. These include direct communication among mobile devices, novel types of end users such as connected vehicles, and a massive number of data flows consisting of periodic, high-frequency, small-sized messages generated by metering or crowdsensing applications.

Figure 2. Average monthly worldwide tablet data traffic transported through Wi-Fi (in blue) and cellular (in green) technologies (Courtesy of Cisco Systems, Inc. Unauthorized use not permitted. Captured from http://www.ciscovni.com/data-meter/ on July 8th, 2014.).

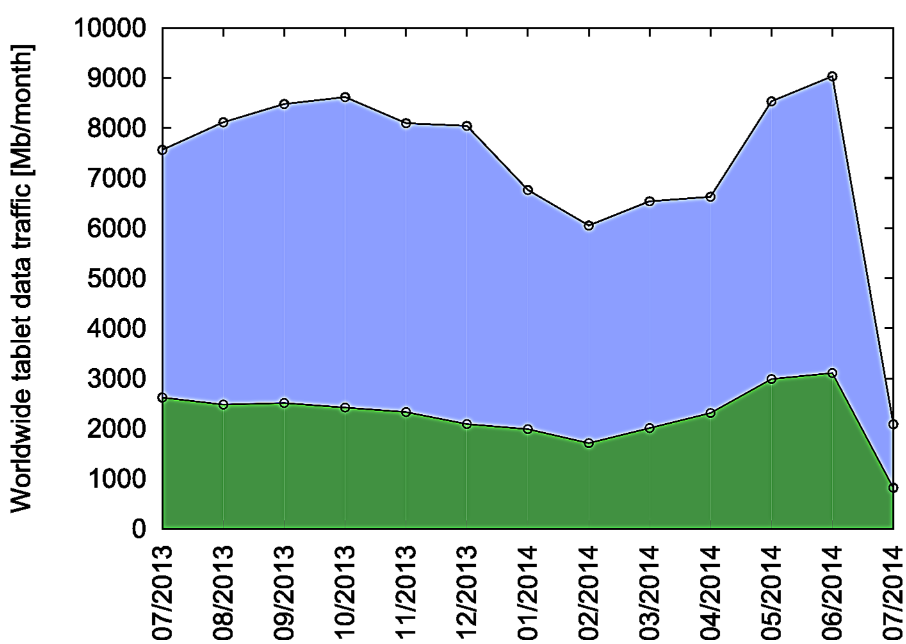
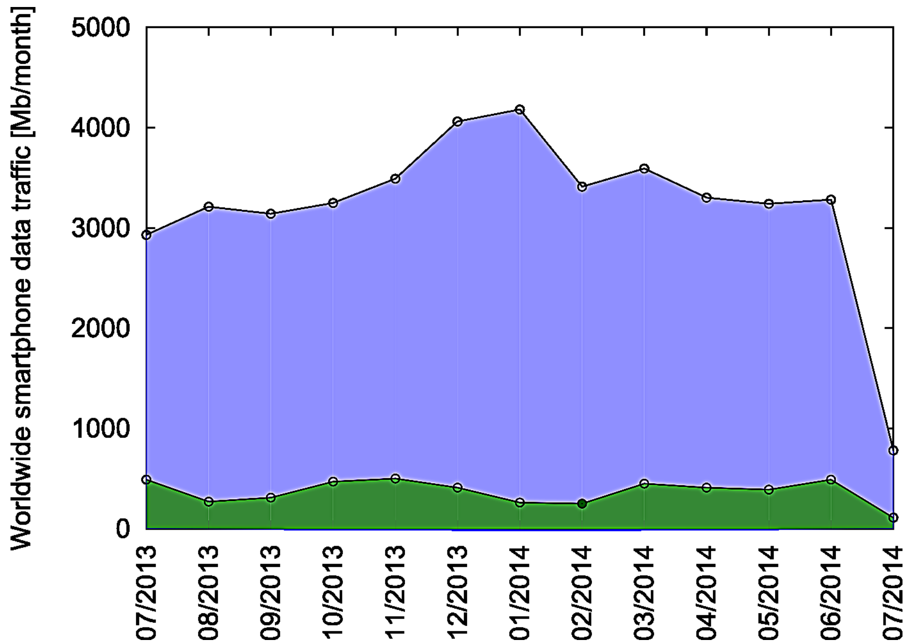


Figure 3. Average monthly worldwide smartphone data traffic transported through Wi-Fi (in blue) and cellular (in green) technologies (Courtesy of Cisco Systems, Inc. Unauthorized use not permitted. Captured from http://www.ciscovni.com/data-meter/ on July 8th, 2014.)



In this section, we discuss the most prominent emerging technologies intended to address the future evolution of mobile traffic, with a focus on smart city services.

Evolution of Cellular Access Technologies

The huge popularity of mobile smart terminals such as smartphones or tablets and the rapid development of mobile services have marked the end of the last decade. This tremendous success was supported by the evolution of 3G cellular networks toward HSDPA, which allowed the support of IP services. In addition, Android, iOS and other mobile operating platforms have greatly facilitated the development and the distribution of mobile applications. Since then, the number of available mobile applications and services has continued to grow exponentially. The ubiquity and multiplicity of mobile services have deeply modified user habits, and most services are now available for mobile users anywhere and anytime. Attracted by the increasing growth of the mobile market and its associated lucrative revenues, new operators have emerged and entered the highly competitive mobile and telecommunication sector, championing novel technologies. Within this context, several consortia composed of mobile ICT actors already anticipated the saturation of 2G and 3G access networks a decade ago. Different technologies began to be proposed at that time as candidates for the fourth generation of cellular networks.

Long Term Evolution (LTE) is the technology that was retained for 4G cellular infrastructures. The first LTE version was specified in 2008 by the 3GPP release number eight, and it was soon considered a 3.9G technology designed to provide a smooth transition to actual 4G systems. As shown in the bottom plot of *Figure 1*, most of the specifications introduced innovations at the radio interface, named eUTRAN. The key elements include Orthogonal Frequency Division Multiple Access (OFDMA), Adaptive Modulation and Coding (AMC) schemes, Multiple Input Multiple Output (MIMO) techniques, beamforming, turbo codes and Hybrid Automatic Repeat Request (H-ARQ).

In 2010, release 10, referred to as LTE Advanced (LTE-A), was recognized by the ITU as a true 4G technology. In addition to some enhancements to the radio interface, such as the capacity to aggregate several carriers, the main novelty of LTE-A lies in replacing the two tier 2G/3G core networks (composed of a circuit switched and packet switch sub-systems) with a unique flat all-IP core network, facilitating the support of IP-based protocols and mobile services. The IP-enabled entities that compose the core network provide operators with the capability to deploy at reduced cost and to manage a 4G infrastructure that can adapt flexibly to customer demand.

LTE/LTE-A operates in conventional 3GPP/3GPP2 bands (e.g. 800/900 MHz), but it also supports many new frequencies between 600 MHz and 3.8 GHz. The allocated bandwidth per operator is flexible and can range from 1.4Mhz to 100Mhz. The theoretical maximum downlink bit rate per user in LTE and LTE-A can attain 300 Mb/s and 1Gb/s respectively.

Overall, many smart city services will rely on cellular access. Specifically, cellular technologies offer anywhere, anytime connectivity that is secure, has QoS guarantees, and enjoys ever-growing bitrates. These features make cellular access the baseline solution for wireless communication in digital urban environments. The main downside, however, remains the economic cost for the end user: to cope with this issue, diverse generations of cellular technologies can be leveraged to satisfy the needs of different applications. For instance, resources (e.g. water, electricity, gas) can be monitored using integrated sensors and GSM chipsets; residential and office building can be managed through M2M services supported by 3G technologies; high-end mobile applications can instead resort to 4G.

Finally, it is worth mentioning the emergence of so-called Ultra Narrow Band (UNB) networks. UNB is a recent technology allowing wireless transfers over long distances (tens or even hundreds of Km) at very low bitrates (10 to 1000 bps). The UNB network architecture mimics that of a traditional cellular network, however the extended communication range makes is possible to dramatically reduce the number of base stations: as an example, the whole of France is covered using just 1000 antennas, whereas the same number of antennas is used in the same country to provide UMTS/LTE access to the city of Lyon alone. In turn, this cuts down capital and operational expenses linked to building and maintaining the network. When compared to traditional cellular systems, UNB technology is also inexpensive from other perspectives. On the one hand, it operates on an unlicensed spectrum (e.g. 868 MHz in Europe and 915 MHz in the US – frequencies often used by cordless phones), which makes it possible to reduce subscription fees to $1 per year. On the other hand, its communication chips are especially cheap to produce, being sold at $1 each today. Clearly, the low bitrate limits the applications of UNB. The technology is thus devoted to so-called Internet of Things (IoT) applications, as UNB could enable Internet connection for countless energy-constrained devices that need to transmit small amounts of information. These include toys, heart rate monitors, energy grid meters, underground pipe monitors, or parking space monitors.

Evolution of Wi-Fi Access Technologies

Nowadays Wi-Fi is the most common wireless access technology in the indoor environment, and it also accommodates a non-negligible share of outdoor-generated mobile traffic. The result is that large portions of urban areas are characterized by a pervasive presence of Wi-Fi APs. Although outdoor Wi-Fi hotspots or WLANs are deployed and managed by operators or companies, in many cases Wi-Fi equipment is installed and configured by private end users, without any coordination. The consequence is the saturation of Wi-Fi channels, especially on the unlicensed 2.4 GHz frequency band. This, jointly with the 54 Mb/s data rate cap of IEEE 802.11a/g, makes current Wi-Fi standards unable to cope with the surge in traffic demand.

IEEE 802.11n

In order to address this situation in 2009 IEEE standardized an enhancement of the IEEE 802.11 family, known as 802.11n. The upgrades make it possible to increase the maximum bit rate per channel to 600 Mbit/s. The major source of improvements lies in the introduction of Multiple Input Multiple Output (MIMO) transmissions: by leveraging the presence of multiple antennae at the sender and receiver, MIMO techniques exploit diversity to make signal reconstruction more efficient and robust to multipath. An introduction to MIMO communication is provided by Tse and Viswanath (2005). The 802.11n standard defines several multi-antenna scenarios, such as 1x2, 3X3, and 4X4.

Another improvement introduced by IEEE 802.11n is the possibility of merging two adjacent 20-MHz channels to form a single 40-MHz channel, basically doubling the maximum capacity of a single data transfer. This allows a further 4% gain, due to the use of the frequency guard band that previously separated the two joined 20-MHz adjacent channels.

Last but not least, IEEE 802.11b/g can only operate at the 2.4 GHz band, whereas IEEE 802.11a only works at the 5 GHz band. IEEE 802.11n allows the user to choose any of these two bands, the main advantage being that of balancing the load among the overcrowded 2.4 GHz band and the not-yet-saturated 5 GHz band. The latter portion of the frequency spectrum also has the advantage of not being subject to interference from the many devices operating at 2.4 GHz, such as Bluetooth, cordless phones, baby monitors, or microwave ovens. Moreover, the number of non-overlapping available channels is much larger at 5 GHz (e.g. 8 in the US) than at 2.4 GHz (e.g. 3 in the US).

IEEE 802.11ac

IEEE 802.11n products are now widely sold at affordable costs. Anticipating the increasing demand for data traffic, in 2014 IEEE announced a new upgrade, called 802.11ac. IEEE 802.11ac targets a maximum cell capacity of 1 Gbit/s and is clearly positioned as a competing technology with the Gigabit Ethernet.

Technically speaking, there is no major technological breakthrough in IEEE 802.11ac. This new evolution of Wi-Fi pushes further the capacity increase already attained in IEEE 802.11n, by allowing the merging of adjacent channels to create 80-MHz and even 160-MHz band channels. Additionally, whereas IEEE 802.11n does not allow MIMO configurations exceeding 4x4, IEEE 802.11ac supports up to 8x8 MIMO. Finally, the denser modulation technique 256QAM is supported by 802.11ac.

Wireless Sensor Communication Technologies

With the turn of the millennium, significant advances in technology for micro-scale electromechanical systems, along with the emergence of low-power wireless communication circuits, enabled the production at industrial level of small-sized, low-cost nodes with sensing, computational and wireless communication capabilities. Akyldiz et al. (2002) provide a first survey of these devices. The deployment of a significant number of sensor nodes – often referred to as *motes* – leads to the formation of a wireless sensor network (WSN), whose goal is to collect information on a physical phenomenon within the supervised geographical area. Nowadays, WSNs are becoming increasingly popular in a number of domains, including the military, medical and environmental sectors. From a different perspective, technologies related to WSNs have also found a large number of applications within the context of smart cities, where they find usage in parking availability monitoring, air pollution monitoring, urban traffic monitoring, or smart street lighting.

The reason for such a success lies in the substantial benefits offered by WSNs: (i) the lack of infrastructure and of associated capital and operational costs; (ii) the self-organization capability of network components, which eases the deployment operation; (iii) the limited cost and size of the sensors themselves, which contributes to both the advantages above. These advantages appear especially profitable for urban applications such as pollution monitoring, public lighting control, smart parking, and smart metering of water, gas, or electricity. A thorough discussion of the potential applications of sensor technologies for smart urban environments, including technical requirements, can be found in (ETSI TR 103055, 2011).

Clearly there are challenges as well, especially in terms of limited resources: the battery lifetime, the communication range, the storage and computation capabilities of sensors are severely constrained, and must be managed carefully – even more so when considering that sensor nodes are typically expected to operate autonomously for timespans from months to years. Fortunately, most WSN-based services concern low-duty-cycle monitoring and tracking, and thus do not require frequent or high-rate data transfers. Driven by the low-power and low-complexity requirements of WSN on one hand, and by the low-data rate and latency requirements of the overlying applications on the other, much attention has been devoted to developing new specifications and protocols at all layers of the protocol stack, as detailed by Wagner (2010), among others.

In the following, we present the main standardized protocols, with a focus on the lower layers of these standards, i.e. the physical (PHY), the medium access control (MAC), and the routing standards, since they are the most relevant in terms of access network technologies.

IEEE 802.15.4 and Upper Networking Stacks

The most popular protocol stack used in WSN architecture is based on definitions provided in the IEEE 802.15.4 standard, which describes the operations at the PHY and MAC layers. It is often coupled with standards that define higher-layer (i.e. network) protocols such as Zigbee or 6LowPan. In order to provide a comprehensive overview, we will first present the IEEE 802.15.4 standard, and then introduce the most popular higher-level standards.

IEEE 802.15.4 was the first open standard designed for low-rate wireless personal area networks (LR-WPAN). The targets of IEEE 802.15.4 are low-complexity and low-power PHY and MAC layer specifications for low data rate wireless communication between low cost devices. At the physical layer, the first version of IEEE 802.15.4, released in 2003, specifies the use of unlicensed bands at 868-868.6 MHz (Europe), 902-928 MHz (North America), and 2400-2483.5 MHz (worldwide) with data rates of 20, 40 and 250 Kb/s respectively (IEEE Computer Society, 2003). The IEEE 802.15.4a standard, released in 2007, introduces enhancements and corrections, along with support for higher data rates; it also reduces unnecessary complexity and considers additional portions of the frequency spectrum (IEEE Computer Society, 2006). In 2009, two new amendments, IEEE 802.15.4c and IEEE 802.15.4d, were released: they mainly introduced two new frequency bands (314-316 MHz and 430-434 MHz).

At the MAC layer, IEEE 802.15.4 defines two channel access modes: a non-beacon-enabled mode and a beacon-enabled one. In the non-beacon-enabled mode, data is transmitted using an unslotted CSMA-CA scheme. Similar to what happens in IEEE 802.11 networks, each node listens to the channel prior to transmitting in order to determine whether the latter is free. If this is not the case, the node waits for a binary exponential back-off before attempting retransmission. In the beacon-enabled mode, a slotted CSMA-CA scheme is used, where a super-frame structure makes it possible to coordinate access to the medium. To that end, a coordinator starts the operations by sending a beacon, which synchronizes nearby nodes and advertises the structure of the super-frame. The latter is composed of: (i) an inactive period; (ii) a Contention Access Period (CAP), where nodes use a slotted CSMA/CA to access the channel; (iii) a Contention-Free Period (CFP), which contains a number of guaranteed time slots (GTS) allocated to specific stations by the coordinator node.

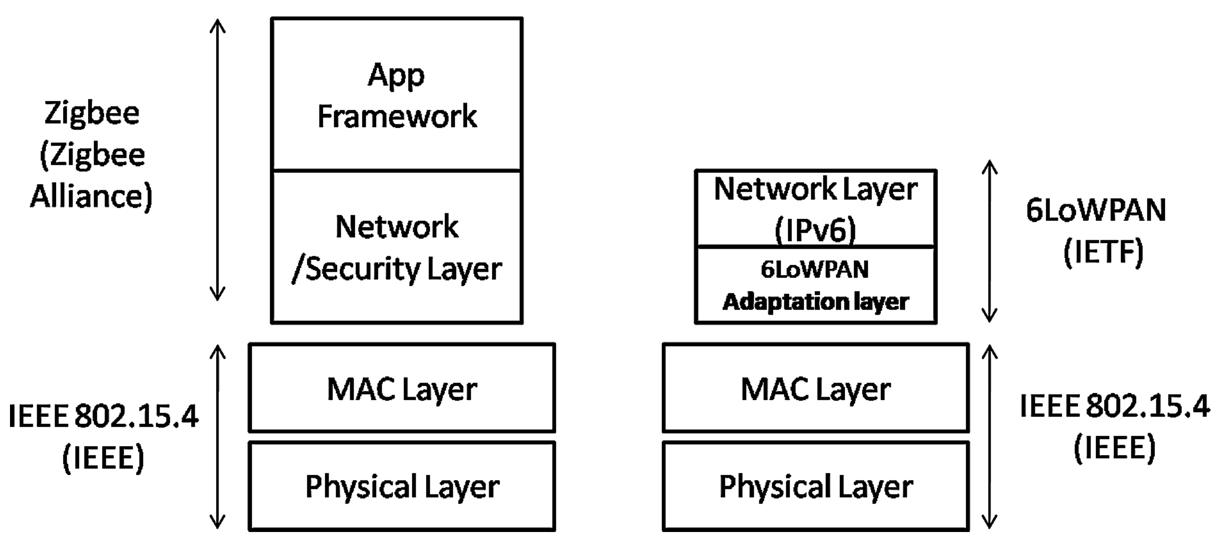
As pointed out above, one of the main design guidelines of IEEE 802.15.4 is the low power consumption. To reach this goal, the standard defines energy-efficient management schemes, mainly including the ability to reach very low duty cycling (i.e. the ratio of the active period to the full active-sleep period). It was shown that most energy consumption at sensor nodes is due to active radio transceivers: therefore, low-duty cycling is the most effective technique to save energy. Beside energy efficiency, IEEE 802.15.4 adapts to time-sensitive WSN applications thanks to the guaranteed time slots (GTS), which are reserved and do not require prior negotiation; these aspects are thoroughly discussed, among others, by Sohraby et al. (2007) and Buratti (2010).

The IEEE 802.15.4e amendment, approved in 2012, introduced some MAC-layer enhancements to the IEEE 802.15.4a standard. It mainly supersedes the use of a single channel mandated by IEEE 802.15.4a, as it favors interference and multi-path fading. Instead, IEEE 802.15.4e introduces a time-slotted channel-hopping mode, which is especially intended for industrial applications.

The success of IEEE 802.15.4 has encouraged the development of many standards to specify upper stacks. Below we present two popular standards, Zigbee and 6LowPan.

Zigbee is a high-level standard-based technology for low-cost, low-power radio devices. It is designed by the industry consortium Zigbee Alliance and is based on the IEEE 802.15 standard, as shown in Figure 4. Zigbee supports both

Figure 4. 802.15.4 and two popular upper stacks: Zigbee (left), and 6LowPan (right)



operation modes of IEEE 802.15.4 presented above. It defines three types of devices: the Zigbee Coordinator (ZC), a single node per network that represents the root of the network tree; the Zigbee router (ZR), which relays packets; the Zigbee End Device (ZED), which runs applications, mainly related to sensing and actuation services. ZED nodes are usually battery-powered and do not relay packets; they are allowed to have very low-duty cycles to reduce their energy consumption and enhance their lifetime.

Zigbee supports three types of topology: star, tree and mesh. The multi-hop routing in tree topologies is guaranteed by a specific address assignment scheme, which makes it possible to deduce the relationships between nodes and their ancestors and descendants. In this way, Zigbee avoids having to build and maintain routing tables. In the mesh topology case, multi-hop routing is performed through an AODV-like reactive routing protocol: the source initiates a route discovery phase by broadcasting a route request, and a shortest path is built using packet loss probability on each link as the cost metric (Zigbee Alliance, 2008). Recently, Zigbee has become increasingly popular in the context of short-range, low-rate WSN applications, including home entertainment and control, building automation, smart parking, and industrial control.

6LowPan stands for low-power wireless personal area networks. It is an IETF working group that aims to adapt IPv6 to support low-cost low-power radio devices. To that end, it builds on top of the IEEE 802.15.4 standard. 6LowPan is motivated by the fact that IP can and should be supported by low-power devices such as sensor and actuator nodes, so as to guarantee their interoperability within a global Internet of Things, as also discussed by Mulligan (2007). The problem statement was introduced in the RFC 4919, as per Kushalnagar et al. (2007), and specifications were released in RFC 4944, as per Montenegro et al. (2007), and later updated in RFC 6282, as per Hui and Thubert (2011).

In order to be able to support IP while reducing energy consumption, 6LowPan offers the following main features. First, it proposes an adaptation layer that makes it possible to fragment IP packets and reassemble them into IEEE 802.15.4 frames. This adjustment is needed since IPv6 packets can be larger than the maximum IEEE 802.15.4 frame size. Second, in order to reduce the length of data packets, 6LowPan proposes to compress the IPv6 header (40 bytes). Third, 6LowPan defines two routing strategies: a mesh-under approach and a route-over one. In the mesh-under strategy, the routing of packets is implemented at the 6LowPan adaptation layer, as shown in Figure 3, based on the IPv6 fragments before the reconstruction. In the route-over strategy, the routing is implemented at the IPv6 layer, where packets are routed after the reconstruction. The mesh-under approach makes it possible to reduce the transmission delay, whereas the route-over strategy is more suitable to loss-prone environments. A detailed discussion is provided by Montenegro et al. (2007), and Hui and Thubert (2011).

Even though 6LowPan presents higher complexity and delay compared to Zigbee, it has recently grown in popularity thanks to the emergence of the Internet of Things and the growing need for interoperability between devices.

DASH7

Although IEEE 802.15.4 and the associated protocols have attracted significant attention, their usage remains limited to significantly localized applications. With these technologies, transmission ranges do not exceed 100 meters, and are more often around 30-40 meters, which may be too limited for many smart city services. This has motivated the development of new standards such as DASH7, which is currently attracting more and more attention. As explained by Norair (2009), DASH7 is based on the standard ISO 18000-7 and is promoted by the DASH7 alliance, an industry consortium formed in 2009. The first standard

DASH7 Mode 2 was announced in 2009 as the next-generation version of ISO 18000-7. Dash7 Alliance Mode Draft 2 was released in 2013 (DASH7 Alliance, 2013).

DASH7 introduces specifications for all the layers of the network stack, from the physical to the application one. At the physical layer, DASH7 operates at the 433 MHz ISM band, where the spectrum is organized into 15 channels grouped into five channel types: Base, Legacy, Normal, Hi-Rate and Blink. These channels have different bandwidths and use different modulation schemes. At the MAC layer, two modes are used according to the channel class. The normal and high-rate classes, referred to as *guarded* channels, are controlled by a CSMA/CA process, whereas access to the other channels, called *non-guarded* channels, can be achieved at any time using a pure ALOHA access mechanism without prior negotiation. For these classes, the use of CSMA/CA is in fact optional.

At the network layer, DASH7 proposes to use a background network protocol called D7A Advertising Protocol (D7AAdvP) and two foreground network protocols, D7A Network Protocol (D7ANP) and D7A DataStream Protocol (D7ADP). D7AAdvP is a broadcast transmission-only protocol used exclusively for fast ad-hoc group synchronization thanks to very short background frames (DASH7 Alliance, 2013). D7ADP is a generic data encapsulation protocol without any addressing or routing information. Communication and routing are thus entirely managed at the upper layers. Finally, D7ANP is an addressable and routable protocol that supports unicast, broadcast, anycast and multicast communication. As an alternative, DASH7 can support IPv6 addressing using a simple adaptation layer, which makes it easily interoperable with other systems. In both cases, we stress that DASH7 specifications define a simple two-hop routing approach and allow integration with other standards like IETF RPL in that sense, as discussed by Weyn et al. (2013).

At the radio level, the main advantage of DASH7 is the good trade-off between the transmission range – reaching up to 2 Km of distance – and the data rate – up to 200 Kb/s, while using low-power communications. This occurs mainly thanks to an operating frequency with good propagation characteristics, and makes it possible to penetrate water and concrete. However, it also mandates the use of larger antennas compared to those employed by technologies adopting higher frequencies.

DASH7 technology has met with significant success over the past few years. As for other technologies, success has been stimulated by military applications: the U.S. Department of Defense awarded a huge multi-million contract for DASH7 devices in January 2009, and NATO is also expected to deploy DASH7 infrastructures. However, DASH7 is also used in several civil applications, with a particular focus on urban services such as home automation and automotive systems.

IEEE 802.11 Power Saving Mode (Low-Power Wi-Fi)

Instead of developing brand new sets of specifications, a different strategy for wireless sensor connectivity lies in the adaptation of well-known standards, via the optimization of their performance in terms of energy consumption. The IEEE 802.11 standard has received a lot of attention in this sense, and a significant amount of work has been devoted to the study of the viability of low-power IEEE 802.11 for wireless sensor networks.

Specifically, modifications of IEEE 802.11 that enable power saving have been proposed both in the case of traditional AP-based DCF communication and in the presence of self-organizing STAs (the so-called *ad hoc* mode). In the presence of an AP, mobile nodes go periodically to a power saving mode where they turn off their transceivers. They then wake up periodically, on a listen interval basis, to check for incoming packets. The AP sends a beacon message at every beacon interval, such that the listen interval is a multiple of the beacon interval. The beacon contains the identifiers of nodes with buffered packets. The latter are assumed to stay awake to receive their packets, as described in Tseng et al. (2002) and Tozlu et al. (2012).

In power saving mode using the ad hoc mode, mobile nodes are supposed to be synchronized and contend at the beginning of the active period to send the beacon packets containing, among other fields, the source address and the destination address of buffered packets. Tseng et al. (2002) showed that the power saving mode initially designed for single-hop ad-hoc communications brings more challenges and complexity in multi-hop networks, mainly due to clock synchronization, neighboring discovery, packet delays, and network partitioning issues.

The use of low-power 802.11 in wireless sensor networks offers the main advantage of native IP compatibility, which facilitates the integration of sensor nodes in the Internet of Things. For this reason, the use of 802.11 may be profitable in single-hop AP-based architectures, such as home environments and building automation scenarios, where sensor nodes send data to a sink while in power-saving mode. However, WSN dedicated standards remain more suitable today for large-scale wireless sensor deployments.

Networked Vehicle Technologies

Increased safety and efficiency in both private and public road transportation is one of the major challenges to be addressed by future smart city technologies. Not only are urban areas growing in terms of population size, but their inhabitants also tend to be increasingly mobile and expect to be able to travel to, from and within cities more and more easily and rapidly. The result is a surge in road travel demand, which can barely be accommodated by traditional solutions, i.e. by augmenting the capacity (e.g. adding lanes to existing roads, or planning and deploying more effective road signalization) and extent (e.g. constructing brand new streets and beltways) of the road infrastructure. Although largely adopted in the past, such practices are now approaching their limits within metropolitan areas in developed countries, where road infrastructures are already very comprehensive, and further physical extensions are unfeasible or unpractical.

A game-changing contribution is thus expected to come from the integration of ICT into road transportation systems. This implies an important goal shift, from increasing the capacity of the road network to using the existing capacity more efficiently – and, incidentally, in a safer way. The objective is to simultaneously reduce road accidents, travel times, and pollutant emission by road vehicles, the three points being clearly correlated. To that end, a number of ICT-enabled smart transportation services are expected to significantly improve our ability to leverage the road infrastructure. These include collision or generic warning notification, reliable and real-time traffic condition information, near-future and long-term anticipation of road network utilization and travel times, traffic light state broadcasting and speed adaptation, automated and transparent tolling, approaching emergency vehicle alert, and nearby point-of-interest advertising.

All of the aforementioned services rely on the capability of vehicles to receive and/or transmit data, anywhere and anytime. They thus depend on the so-called *networked vehicle* principle, i.e. equipping vehicles with one or more wireless communication interfaces, so that they are fully integrated within the smart city telecommunication network. Multiple radio interfaces may be needed on each vehicle since different services entail diverse information sources and destinations: for example, live traffic information services rely on information generated by an Internet-based server (or, as some may refer to it, in the Cloud), which then needs to be multi-casted to subscriber vehicles; on the contrary, collision notifications concern circumscribed geographical areas and have tight delay constraints, which makes direct communication among vehicles a more fitting option.

As a result, the vehicular communication environment requires that different wireless networking approaches are taken in parallel. Here, the main distinction is between services that need pervasive access to remote resources, and those that require localized access. The former are expected to leverage the existing cellular infrastructure, whereas the latter depend on dedicated communication paradigms that are specific to vehicular environments. Below we present architectures following these two paradigms and discuss the associated access network technologies separately.

Cellular Communication-Enabled Vehicles

Vehicles can easily be equipped with cellular radio interfaces and exploit the existing 2G/3G/LTE infrastructure to send/receive data. This approach to vehicular networking is especially convenient in the case of services provided by or requiring the intervention of servers on the Internet. In fact, its implementation is trivial from a technical viewpoint, and the first networked cars embedding cellular interfaces are already on the market. Moreover, the integrated interfaces can be easily replaced by those already available on, for example, smartphones or high-end navigation systems present onboard, which dramatically increases the penetration rate of the technology at basically no cost.

As a result, cellular access is the current de-facto standard in communication-enabled vehicles, and a number of already deployed services rely on a vehicle-to-cellular infrastructure data transfer model. One example is that of *remote monitoring* of vehicle status, a service offered by many automobile manufacturers, e.g. BMW Assist, Ford SYNC, General Motor OnStar, Toyota Safety Connect and Mercedes-Benz mbrace, to cite a few. Another successful application is that of quasi-real-time traffic estimation and notification, where vehicles act as mobile sensors in a *crowdsensing* system, by periodically communicating their speed and direction (and possibly information about accidents, road works, etc.). This information is gathered and processed by a central controller, and finally broadcasted back to the vehicles, which thus have an up-to-date vision of the road traffic conditions (TomTom, 2010). A final example is provided by insurance services: by installing *black boxes* on vehicles, the behavior of drivers can be constantly monitored, and liability can be determined in case of accidents.

All the services introduced above require information from vehicles to be uploaded to the Internet. Their success raises two main questions. The first is of economic nature. Cellular communication occurs on a licensed spectrum, and has thus a financial cost. The question concerns which of the entities involved (the service provider, the car manufacturer, the telecommunication operator, or the end user – either directly or indirectly) will pay for such a cost. In other words, business models must be identified that make cellular access by vehicles economically viable. The second question is instead technical, and it is thus of more interest within the context of this Chapter. It concerns how to accommodate vehicle-generated data – typically referred to as Floating Vehicle Data, or FVD – through cellular upload. Sommer et al. (2010) and Bazzi et al. (2011) have considered exploiting the Random Access Channel (RACH) of 3G UMTS access networks. RACH is a shared direct-access channel normally employed for signalization; however, by transmitting small-sized FVD directly on RACH, rather than asking for a dedicated channel, vehicles reduce delays and increase communication efficiency. The solution appears viable, yet important issues also exist: only a few tens of small packets can be uploaded per second within each cell, RACH does not support inter-cell handover (which occurs frequently in the case of high-speed vehicles), and the solution generates RACH congestion – thus reducing the

QoS of traditional mobile voice and data services. Mangel et al. (2010) and Ide et al. (2012) have instead studied the impact of FVD on LTE access networks technology. Although better performing than UMTS, LTE also has limitations when it comes to FVD upload: specifically, it suffers delays of up to 50 ms and its capacity is constrained to 100 packets per second on a dedicated 5-MHz channel.

In order to mitigate the effect of FVD on cellular access networks, Stanica et al. (2013) and Ancona et al. (2014) have suggested complementing cellular communication with dedicated vehicle-to-vehicle communication. The latter is also a more fitting technology in the case of information dissemination constrained to vehicular devices, i.e. where the data is generated by, and destined to vehicles. Here, cellular communications do not appear a convenient solution, as they force the content to unnecessarily transit (twice or more) through the radio access network. Below we describe dedicated wireless technologies enabling direct and distributed communication among vehicles.

Dedicated Communication-Enabled Vehicles

Wireless communication technologies dedicated to vehicular environments have not yet hit the market, even though they feature a very long history of research and development with its roots in early proposals during the 1970s. Prototype solutions were developed in parallel in the USA, with the Electronic Route-Guidance System (ERGS) introduced by Rosen et al. (1970), based on vehicle-to-instrumented intersection communication, as well as in Japan, where the Comprehensive Automobile Traffic Control System (CACS) national project (launched in 1973), targeted the same road efficiency goals we still pursue today. A number of activities in the USA, Japan and Europe followed during the next 30 years, and Hartenstein and Laberteaux (2008) provide quite a complete overview of the field. However, the limitation of wireless technologies available at the time, the complexity of shifting the whole automotive industry towards the networked vehicle paradigm, the excessive costs of building the dedicated roadside infrastructure needed by many proposed architectures, and the lack of ultimate proof of the effectiveness of dedicated vehicular communications led to a failure to bring these proposals to the industrial production stage.

At the turn of the century the study of vehicular communication technologies started to gain momentum. This was due to the combination of two main factors: first, the success of IEEE 802.11 as a local area network technology, which demonstrated how high-performance wireless communication could be easily and widely deployable; second, the allocation of a reserved frequency band for Dedicated Short-Range Communication (DSRC) in vehicular environments, first in the USA and subsequently in Japan and Europe. As a result, adapting the IEEE 802.11 standard to operate in the DSRC frequency band appeared as a convenient solution to finally enable vehicular communication.

According to the specifications of the US Federal Communications Commission (FCC), the DSRC spectrum consists of 75 MHz at 5.9 GHz, divided into seven 10-MHz channels, with the lower 5 MHz reserved as a guard band. Two pairs of channels can be combined into 20 MHz channels, as per the diagram. One of such channels, namely channel 178, is designated as the Control Channel (CCH), whereas all the others are Service Channels (SCH). The former is intended for signaling purposes and for broadcasting information relevant to all vehicles. The latter are designated for specific services provided or consumed by vehicles. Transmission power can reach 28.8 dBm for an expected communication range of 1 km. We note that experimental assessments, such as those carried out by Bai et al. (2010) and Martelli et al. (2012) have found such ranges to be rather optimistic, with practical communication distances falling in the 50-300 m range. In Europe, the European Commission has standardized a slightly different spectrum allocation, with a reserved band limited to the three central channels of the FCC specifications. These are also referred to as the ETSI ITS-G5 channels.

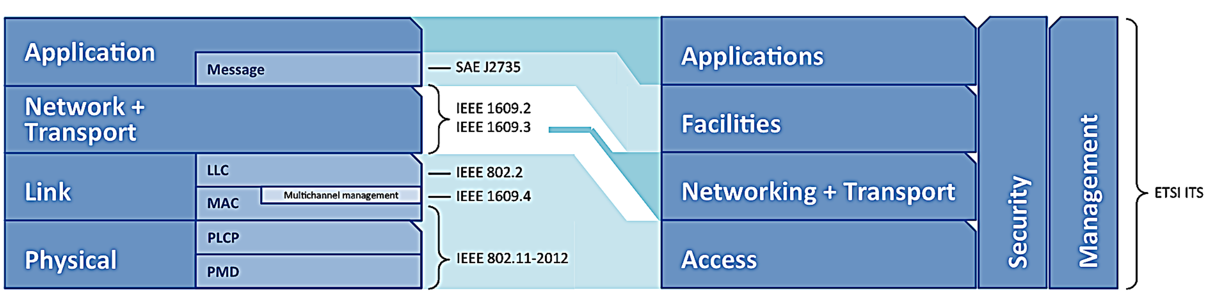
Building on such dedicated spectrum availability, ten years of standardization efforts have led to different bodies producing several specifications. *Figure 6* presents the network protocol stacks proposed by IEEE and ETSI.

The IEEE stack, on the left in *Figure 6*, is expected to be adopted in the US, and is based on different protocol families. The Physical (PHY) layer and Medium Access Control (MAC) sublayer are direct evolutions of those described in the popular IEEE 802.11 standard for wireless local area networks. The draft standard for DSRC has long been known as IEEE 802.11p, however such an amendment has recently been superseded and its features included in the latest release of the IEEE 802.11 standard, known as IEEE 802.11-2012. Since the legacy IEEE 802.11 standard and its different variants have been described previously in this Chapter, here we limit ourselves to highlighting the main features inherited from IEEE 802.11p that have been included in IEEE 802.11-2012:

- Compliance with the 10-MHz PHY channel structure dictated by FCC specifications.
- An *ad-hoc* communication mode outside the context of a Basic Service Set (BSS), i.e. the elementary building block of IEEE 802.11 networks, typically managed by an Access Point (AP). This mode allows direct communication between any device, removing the association and authentication phases: these are time-consuming operations that are not compatible with the short-lived links established by high-speed vehicles.
- Adoption of the Quality of Service (QoS) specifications introduced earlier by amendment IEEE 802.11e, concerning the use of four traffic priority categories that devices can use to access the channel, depending on the kind of data they have to transmit.

The management of the multiple available channels in *Figure 6* is constrained by the availability of a single radio interface at each vehicle, and IEEE 1609.4 describes its operation. The standard recommends that all vehicles – synchronized via GPS, for example – alternately listen (or transmit) on the CCH and on a SCH of interest according to a time-division mechanism. More precisely, time is divided into 100-ms intervals, during which all vehicles spend the first 50 ms on the CCH and the next 50 on a SCH. This approach has long been questioned by the research community, due to the latency and temporal unbalance in the channel access load it may generate; different approaches have thus been proposed, such as those by Campolo et al. (2011) and Di Felice et al. (2012).

Figure 6. DSRC protocol stack according to IEEE and ETSI specifications

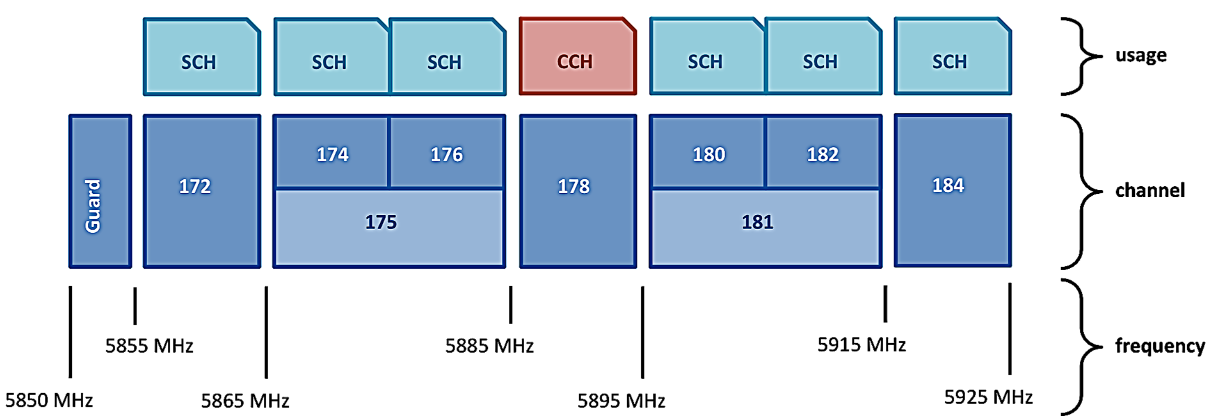


At the network and transport layers, the complexity of the traditional TCP/IP model is deemed useless in vehicular environments, where long-lived unicast flows are absent. Therefore, the IEEE 1609.3 standard replaces TCP (or other transport protocol) and IP headers and operations with a much more compact message structure. The resulting WAVE (Wireless Access for Vehicular Environments) Short Message Protocol, or WSMP, makes it possible to: (i) reduce the packet overhead from the 52 bytes of TCP/IPv6 to 11 bytes; (ii) control lower-layer parameters directly from the application layer, as the data transmission rate, the transmit power, and the channel number can be explicitly indicated in the WSMP packet. The IEEE 1609.2 standard integrates IEEE 1609.3, by defining the security measures to be adopted to ensure privacy, authentication and integrity of data exchanged via DSRC. Finally, the SAE J2735 standard defines a DSRC message set dictionary, i.e. a list of standard message types that can be used to exchange different kinds of information in the vehicular network.

The ETSI stack, on the right in Figure 5, is expected to be adopted in Europe, and it is based on a single standard called ETSI ITS. The ETSI ITS standard was developed after the different protocols that compose the IEEE stack, and thus makes large reuse of mechanisms defined in the IEEE stack – also to ensure compatibility between DSRC implementations in the US and Europe. Specifically, the *access* layer of ETSI ITS, built on top of the ITS-G5 channels mentioned before, covers PHY and MAC specifications, and basically relies on the specifications of IEEE 802.11-2012. The *networking and transport* layer accommodates any layer-3 and layer-4 solutions, including TCP/IP, those specifically defined by IEEE 1609.3, and so-called Geo-networking solutions introduced by ETSI itself. The *facilities* layer implements all functions that support interoperability between the vehicular network and external systems, such as those composed by in-vehicle electronic control units or roadside units. As such, this layer specifies periodic (Cooperative Awareness Messages, or CAM) and event-triggered (Decentralized Environmental Notification Messages, or DENM) messages that can be used for road safety and traffic management purposes. The ETSI architecture also includes additional *security* and *management* layers that are orthogonal to the previous layers, and define (i) cryptographic and algorithmic solutions to guarantee secure operations, and (ii) interfaces among the different layers respectively.

The IEEE and ETSI architectures have served as a basis for the development of a large body of

Figure 5. 5.9-GHz frequency spectrum reserved for DSRC by FCC



literature on applications, algorithmic solutions, and protocols dedicated to vehicular environments. Many of these are targeted at road safety, and implement services such as collision avoidance, on-road danger warning, approaching emergency vehicle notification, real-time traffic congestion information and routing, and accident liability attribution. Others are not directly related to road safety and include the dissemination of content to users onboard cars, the unicast routing of data within the vehicular network, the deployment of DSRC-based roadside units, the gathering, fusion and exploitation of FVD concerning the vehicles themselves as well as the surrounding environment, making vehicles active participants of urban sensing processes. A thorough discussion of the many and varied works on specific aspects of communication and networking techniques for vehicular environments would require a book per se, and is out of scope in the brief overview we provide here. We refer the interested reader to complete volumes on these subjects, such as those by Olariu and Weigle (2009), Moustafa and Zhang (2009), Hartenstein and Laberteaux (2010), and Beylot and Labiod (2013).

Direct Mobile Device Communication Technologies

Direct communication between wireless devices is an important opportunity to offer new, cheaper services to mobile end users. This communication paradigm bypasses operators, which are instead at the center of traditional mobile network models, and allows two devices in proximity to directly exchange data traffic. Moreover, as the mobile traffic load grows, even cellular operators are beginning to integrate device-to-device communication capabilities in their architectures, so as to meet user demand more effectively. Below we provide a survey of currently available technologies providing direct connectivity between mobile devices.

Bluetooth 3.0 and 4.0

Legacy Bluetooth has been the main technology used for device-to-device communication for a long time. Integrated in all mobile phones for more than a decade now, Bluetooth interfaces allow file exchange, data synchronization and the connection of peripheral devices. Originally standardized by the IEEE as the 802.15.1 standard, Bluetooth specifications are now defined by the Bluetooth Special Interest Group (SIG), while the IEEE working group is no longer maintained.

Bluetooth operates on the 2.4 GHz band, and proposes a centralized medium access method, where a master node forms a so-called *piconet*, which can be joined by up to seven slave nodes. The master node is in charge of regulating access to the wireless channel, and thus polls the slaves, granting them transmission opportunities. The Bluetooth standard describes not only the channel access technology, but also an entire communication architecture. Specifically, the protocol stack is divided into two parts: the *controller stack* and the *host stack*. The controller stack includes the physical and link layers, usually implemented on the chipset, while the host stack covers upper layers, including mandatory and optional protocols. The two host mandatory protocols are the Logical Link Control and Adaptation Protocol (L2CAP) and the Service Discovery Protocol (SDP).

In the last few years, Bluetooth has been adapted to two different scenarios. First of all, wireless technology is required to interconnect devices in a home network, more and more popular for audio and video streaming. While Bluetooth interfaces were present on most devices, the throughput offered by the technology was not enough for video streaming purposes. Bluetooth 3.0, a standard published by the SIG in 2009 (Bluetooth SIG, 2009), addresses this issue by reaching a theoretical throughput of 24 Mb/s. However, these high data speeds are not actually provided through the Bluetooth interface. Instead, Bluetooth

3.0 introduces a Generic Alternate MAC/PHY (AMP) concept, in which Bluetooth is used for the negotiation and establishment of a collocated IEEE 802.11 link, used for data transmission. Initially, Bluetooth 3.0 adopted IEEE 802.11g as an alternative technology, with IEEE 802.11n being added as an alternative in 2011.

A second important Bluetooth use-case is represented by the Internet of Things, an interconnection of small wireless nodes, which are very often energy constrained. Traditional Bluetooth proposes a connection-oriented link layer, where a link created between devices is maintained until an explicit disconnection, even if there is no data flowing between the two connected devices at a given time. Based on the observation that this mode of operation consumes a significant amount of energy, Bluetooth 4.0 describes different energy saving mechanisms (Bluetooth SIG, 2013). The new features include a totally redesigned PHY layer with larger channel bandwidth, and an asynchronous connection-less MAC protocol. Bluetooth 4.0 achieves a throughput of up to only 1Mb/s, but it is optimized for small, discrete data transfers, ideal for small, energy-constrained nodes, such as those forming a wireless sensor network.

With these two adaptations, new Bluetooth-based applications are expected to emerge. The increased throughput in Bluetooth 3.0 is particularly interesting for video and audio streaming, and also for file exchange, either in the context of a home network, or to interconnect personal devices (e.g. transferring photos or contacts between smartphones, use on a smart-watch content stored on a smartphone, watching videos from a tablet directly on a smart-TV, etc.). At the same time, Bluetooth 4.0 is expected to have a significant impact on the personal fitness and health market, by allowing devices such as smart-watches or electronic bracelets to monitor human activity and upload data to more powerful personal equipment, such as a smartphone or tablet.

LTE Direct

Despite the significant challenges that such a shift brings, device-to-device communication is on the verge of breaking into cellular network architectures. Pushed by the exploding adoption of smartphones and the dramatic growth of data traffic, cellular operators are considering utilizing direct communication in order to offload data from their network, especially in the context of ambient awareness, i.e. the continuous and passive monitoring of relevant phenomena in the user's proximity.

The LTE Direct system operates on a licensed spectrum and it is composed of two main functions: Device-to-Device Peer Discovery and Device-to-Device Data Communication. In Peer Discovery, described in more detail by Lin et al. (2014), a small part of the time-frequency resource, generally less than 1%, is dedicated to LTE Direct discovery. This is based on the concept of *expressions*, which describe the services proposed by a device and are transmitted using the discovery resources functionality. The cellular Radio Access Network (RAN) assigns these discovery resources to authorized LTE Direct devices. In practice, the devices broadcast their expressions locally using 128-bit identifiers, then wake up periodically to discover all devices within range that are interested in the services it may offer.

Once the discovery phase succeeds, two devices that detected a common expression need to communicate with each other. The cellular network is used in this case for control-plane operations, such as synchronization, configuration or authentication, while the actual communication can take place either through the cellular network, or directly between the devices. The RAN controls the communication type in order to optimize network capacity, and assigns the necessary time-frequency resources in both situations. LTE Direct has a very high discovery capacity (almost 3000 services can be discovered in only 64 ms), with a negligible impact (0.3% reduction) on LTE uplink capacity.

LTE Direct can be used to disseminate information with a local geographic scope, such as service advertisements or coupons. Restaurants and shopping centers are expected to adopt the technology widely for marketing purposes. LTE Direct can also be used to interconnect vehicles in a certain area, covering safety and road monitoring applications, as explained by Gallo and Härri (2013).

Wi-Fi Direct

The first version of the IEEE 802.11 standard proposed an ad-hoc mode. The main concept used in ad-hoc mode consisted of a normal device declaring itself to be an Access Point (AP), allowing communication with other devices in a transparent manner. However, the IEEE 802.11 ad-hoc mode had limited success, especially because of the difficulties of inter-connecting an ad-hoc network with other IEEE 802.11 networks.

Indeed, in IEEE 802.11, the access points broadcast a so-called *Basic Service Set (BSS) identifier*, generally defined as the MAC address of the AP. A Wi-Fi device attaches to a BSS and, while the device can switch from one BSS to another, it must be connected to a single BSS at a given time. In the case of an ad-hoc Wi-Fi network, the device that becomes an AP cannot leave the BSS it has created, and the other devices cannot belong to more than one BSS, so communication will remain local, without any possibility of exiting the BSS.

With the IEEE 802.11 working groups reluctant to modify this feature, the Wi-Fi alliance decided to define its own specification for device-to-device communication using Wi-Fi, under the name of Wi-Fi Direct (Wi-Fi Alliance, 2014). Just as in IEEE 802.11 ad-hoc mode, a Wi-Fi Direct device embeds a *soft AP*, which allows it to act as an access point. The main difference comes from the fact that the device can belong to two BSS at the same time, once as an AP and once as a normal station. A device in this situation needs to switch between the two networks, very likely established on different physical channels. However, while the device acts as a normal station on the second network, the first network remains practically without an access point. In order to stop any data exchange in the network during an absence period, the AP device uses a virtual carrier sense mechanism to declare the medium as busy for all possible transmitters.

Due to these enhancements, Wi-Fi Direct has already replaced IEEE 802.11 ad-hoc mode in the market, and is already integrated into most commercial mobile devices. Wi-Fi Direct is considered a solution to provide fast wireless connections to peripherals (e.g. printers, displays, speakers, scanners, cameras, etc.), while still being connected to an AP, which is impossible with traditional Wi-Fi. File sharing applications could also benefit from Wi-Fi Direct, particularly in scenarios where two-way data transfer between multiple devices is needed.

Ultra-Wide Band

With communication becoming possible at higher frequencies of the radio spectrum, previously unused large portions of spectrum can be used. Ultra-Wide Band is a radio technology that makes use of this available spectrum, and is able to achieve high-speed short-range communications. UWB was intensively researched in the early years of the millennium, with several standards being adopted (ETSI, 2004). While the expected market breakthrough did not occur, interest in UWB was revived by potential uses in wireless sensor networks, as pointed out by Zhang et al. (2009).

Unlike traditional radio technologies, which use the signal's power, frequency or phase to modulate information on a narrow band channel, UWB transmits *pulses* on a large bandwidth (over 500 MHz) channel using pulse-position or pulse-time modulation. This allows throughputs of up to 1 Gb/s over distances of a few meters, under line-of-sight conditions.

This type of pulse-based UWB has long been used for radar and imaging systems. This brings an important advantage to the technology, as the same signals can be simultaneously used for communication and localization purposes. Due to this property, UWB is a good candidate technology for surveillance and monitoring systems. When the 60GHz band is used to transmit information, the pulses do not penetrate the human body, making UWB suitable for body area networks, used for example by eHealth applications. On the other hand, when functioning at lower frequencies (between 3 and 10 GHz), the pulses can penetrate through intervening bodies, making UWB particularly appealing for connecting peripherals to a computer, for example by using the Wireless Universal Serial Bus (USB) standard (USB Implementers Forum, 2010).

Near Field Communication

Radio-Frequency Identification (RFID) is a technology allowing a reader device to send radio waves to a passive device, also known as a *tag*. The tag uses the radio waves to recover energy and modulate locally stored information, which is transmitted back to the reader, allowing identification and authentication applications. Near Field Communication (NFC) builds on RFID standards (ISO/IEC/ECMA, 2013) to achieve two-way communication, allowing for low-speed data transfer over very short distances (less than 10 cm).

NFC is especially used in contactless payment systems, but also as an access token for restricted areas. Another important use of the technology takes advantage of its low-energy consumption: NFC can be used to detect the proximity of another device and activate energy-consuming interface, such as Wi-Fi Direct, for a high-speed data exchange.

A number of wireless communication technologies have been proposed in the last few years for direct device-to-device data transfer. These technologies cover many different scenarios, from communication ranges of a few centimeters (NFC), up to several hundred meters (LTE Direct), and from transfer speeds of a few Mb/s (Bluetooth 4.0), up to more than 1 Gb/s (Wi-Fi Direct, UWB). With commercial smartphones already integrating interfaces for several of these technologies, device-to-device communication is only waiting for the *killer application* to change the urban networking paradigm.

FUTURE RESEARCH DIRECTIONS

In the previous section, we reviewed wireless access technologies for smart cities. Table 1 summarizes the main features of such technologies, as well as their expected usages in digital urban environments. In the light of our discussion, we draw the following main considerations.

- Firstly, network paradigms – including the associated communication technologies – for the wireless last mile cannot be studied in isolation from each other, but must be fully integrated, so as to achieve a coherent deployment that leverages the strengths and makes up for the deficiencies of each networking approach.
- Secondly, network architectures for the wireless last mile cannot be separated from the application use cases, nor can they be specific to one single application, but they must be designed with a clear set of requirements from the largest possible number of smart city services in mind.
- Thirdly, network solutions for the wireless last mile of smart cities cannot be abstracted from the urban tissue, but must be developed and evaluated considering the geography of metropolitan areas, as well

as the spatiotemporal dynamics of human mobility, habits and interests that characterize them.

These observations lead to the introduction of a novel, unifying networking paradigm for wireless access in smart urban environments. We refer to it as *capillary networking*, a term that is reminiscent of the pervasive penetration of different technologies for wireless communication in future digital cities. Indeed, capillary networks represent the very last portion of the data distribution and collection network, bringing Internet connectivity to every endpoint of the urban tissue in the same exact way capillary blood vessels bring oxygen and collect carbon dioxide at tissues in the human body. Capillary networks inherit concepts from the self-configuring, autonomous, ad hoc networks so extensively studied in the past decade, but they do so in a holistic way, considering multiple technologies and applications simultaneously and accounting for the specificities of the urban environment.

Capillary Networks

Capillary networks employ manifold wireless communication technologies to provide a flexible link between the core network and mobile devices. The different access paradigms discussed above come together and are strongly intertwined within capillary networks, coexisting and co-operating in the context of arising digital cities. As argued by Augé-Blum et al. (2012), this has three major implications, as follows.

Firstly, capillary networks arise from the interaction of all the technologies that are part of it. As an example, state-of-the-art smartphones

Table 1. Summary of wireless technologies for smart cities, ordered by achievable bitrate

Technology	Range (m)	Bitrate (Mbps)	Applications
GSM	< 35000	0.0144	voice, sms
GPRS/EDGE	< 35000	0.144	email, machine-to-machine, telemetering
UMTS	< 100000	2	web browsing, social media
HDSPA	< 100000	40	streaming, smartphone applications
LTE/LTE-A	< 100000	300-1000	broadband mobile Internet access (streaming, cloud services, pervasive access, high-mobility device connectivity)
IEEE 802.11 a/b/g/n/ac	100-500	1-1000	broadband Internet access, local area networks, home networks
Wi-Fi Direct	100-500	1000	peripherals connection, file transfer
UWB	< 10	1000	surveillance and monitoring, peripheral connection
Low Power Wi-Fi	25	1-54	home control, building automation
Bluetooth 3.0	10-100	24	video streaming, peripheral connection, file exchange
DSRC	50-1000	3-27	road safety, traffic management, vehicular communications
Bluetooth 4.0	10-100	1	personal fitness, eHealth, sensor networks
LTE Direct	500	1-10	service discovery, vehicular communications
NFC	< 1	1	ePayment, access restriction, device discovery
IEEE 802.15.4	75	0.25	home entertainment and control, building automation, smart parking, and industrial control
DASH7	250-1000	0.02-0.2	military applications, monitoring, building automation, in-vehicle automotive services
UNB	undisclosed	0.001	very low bitrate Internet-of-Things services

integrate a growing number of sensors (e.g. environment sensing, resource consumption metering, movement, health, noise or pollution monitoring) and multiple radio interfaces (e.g. 3G, LTE, Wi-Fi, Bluetooth, NFC, etc.): all these sensing and communication capabilities must be considered as a whole when designing services as well as the network solutions deemed to support them. Similar trends are also observed in privately owned vehicles (TomTom, 2010), public transports as outlined by Zu et al. (2009), commercial fleets (Cabspotting, 2014), and even city bikes (Copenhagen Wheel, 2014). In the same way, access network sites tend to implement heterogeneous (e.g. 2G, 3G, LTE, Wi-Fi, etc.) communication technologies so as to limit capital expenses. There is thus a need for holistic approaches to the study and deployment of capillary network solutions.

Secondly, the capillary network paradigm necessarily accounts for the specificities of urban environments. These include actual urban mobility flows, city land-use layouts, metropolitan deployment constraints, and routine or extraordinary activities of the population. Often, these specificities do not arise from purely networking features, but relate to the study of city topologies and road layouts, social acceptability, transportation systems, energy management, or urban economics.

Thirdly, the scope of digital and smart cities applications is not restricted to Internet of Things use cases supported by Machine-to-Machine (M2M) communications. Indeed, a city is, above all, the gathering of its citizens. Digital services and mobile Internet are primarily used to increase the quality of life, empowerment, and entertainment opportunities for citizens. Communication patterns in smart cities are thus not restricted to M2M. In some cases, data flows should be gathered to, or distributed from, a centralized information system. In other situations, data should be disseminated within a geographically or temporally constrained perimeter. Future usage may even lead to direct data exchange among neighboring end users. These user-centric services are tightly correlated with the usage of the urban environment, which induces a strong spatial and temporal heterogeneity in data traffic patterns.

As a result, a number of open issues remain to be addressed, in order to turn the large set of currently available communication interfaces and infrastructures from a mass of independent technologies into an actual capillary network, capable of answering the challenges of the smart city.

Open Issues

The urban environment is especially challenging for wireless networking technologies, yet capillary communications need to take place at the heart of urban activity. Current research activities seldom consider the unreliability of radio links or the heterogeneity of the urban environment when proposing dedicated solutions for smart city access networks. An important challenge is thus that of properly understanding and characterizing the fundamental features of urban capillary networks. These include the network infrastructure topologies, the dynamics of user mobility and activities, and the traffic patterns generated by smart city services. Models and datasets are required for the evaluation of relevant scenarios of urban networks, as proposed by Uppoor et al. (2014) for the case of vehicular mobility.

In terms of pervasive urban sensing, a major challenge lies in shifting the current common practice of designing a dedicated sensor network for each application. Such an approach would not scale, and needs to be superseded by the rise of multi-service data collection networks capable of fulfilling the QoS requirements of each application. The notion of Service Level Agreement (SLA) for traffic differentiation, QoS support (in terms of delay, reliability, etc.) is central here, both for scalability purposes and resource-sharing effectiveness. A proper definition of this notion and the related network mechanisms, in particular in the settings of low-power wireless devices and mobile Internet-of-Things devices, needs to be developed, as proposed by Gaillard et al. (2014). Furthermore, even though they are not designed to carry such low payload traffic, cellular networks could be used to collect M2M traffics. In particular, when a cell is fully loaded or, at the other extreme, when there are few access requests, there is a considerable amount of small, unused bandwidth slots on the random access RACCH channels. The challenge is then to piggyback few bits of data within the access signaling procedures, without saturating the resources needed by legacy mobile users.

More generally, QoS must be accounted for at both MAC and routing layers. Recent proposals, such as those by Barthel et al. (2012), target the improvement of QoS performance while preserving energy efficiency. Yet, for critical applications, QoS performance is not enough: in this case, fully deterministic protocols are needed so that worst-case delays can be predicted, as done, for example, by Mouradian et al. (2014).

Significant challenges also emerge with respect to network robustness and energy efficiency. As a matter of fact, the dramatic increase in mobile data traffic imposes an ever-growing densification of micro-cell coverage, as pointed out by Fehske et al. (2009), which raises energy issues. Indeed, current 3G and LTE eNodeB's or relays, whatever their state – idle, transmitting, or receiving – are known to drain a vast majority of the power consumed within the mobile network; moreover, this represents a growing trend (ITU, 2014). For a sustainable deployment of the micro-cell infrastructure which does not lead to a surge in the access network energy consumption, but yields instead a significant decrease in the same, an operator has to be able to dynamically switch on or off radio access equipment depending on mobile demand, as originally indicated by Marsan et al. (2009). To this end, self-organization mechanisms typically proposed for wireless sensor networks can be adapted to the energy models of the micro-cells and the requirements of the cellular infrastructure, as proposed by Tunaru et al. (2013). Again, the main challenge lies in designing and assessing solutions with realistic environmental conditions in mind, including infrastructure deployment, the geographical coverage of each antenna, or mobile traffic demand.

Energy efficiency is an open issue not only in the case of cellular networks, but also when it comes to sensing infrastructures. Here, an interesting approach to solving the problem is energy harvesting, which can significantly increase the network lifetime by allowing nodes to recharge over time using power sources made available by the surrounding environment.

Finally, the sheer growth in mobile traffic demand will represent a problem per-se in years to come, and the issue will be more evident in urban scenarios where user density is significantly higher. In this regard, the capillarity of heterogeneous wireless access networks needs to be leveraged so as to diversify the routes data take and balance the load among the different infrastructures. The ubiquity of Wi-Fi access in urban areas makes it an especially interesting solution to cellular offloading, and many studies, such as that by Lee et al. (2010), have focused on its potential, concluding that more than 65% of the data can be offloaded from the cellular infrastructure in high-density areas. However, most public Wi-Fi networks are optimized for connectivity and not for capacity: more research is needed in this area to correctly assess the potential of this technology. Moreover, handovers among diverse technologies are currently managed by mobile terminals alone, and more efficient results might be achieved if the client and network sides collaborated in taking decisions about such vertical handovers. Direct opportunistic communication between mobile users can also be used to offload an important amount of data, as stressed by Han et al. (2010). In this case, one has to face a number of major problems concerning the role of social information and multi-hop communication in the achievable offload capacity. Finally, the last key challenge related to accommodating mobile data traffic demand is the deployment of an architecture of hotspot access points tailored for user-centric applications, including urban sensing or connected vehicles.

CONCLUSION

In this Chapter, we overviewed current and future technologies providing communication and networking support to smart city services. The infrastructures contributing to such an effort are many and varied, and this heterogeneity can be both a richness and an impediment towards the deployment of pervasive smart city solutions. On the one hand, the availability of wireless access technologies with diverse properties makes it possible to support applications with dissimilar requirements. On the other hand, deploying a large number of independent network infrastructures based on mutually blind technologies is hardly a possibility, due to interference on the shared portions of the spectrum and the multiplication of capital and operation expenses.

The solution lies in reducing mobile access technologies to a limited set with orthogonal properties, and – most importantly – designed with interoperability in mind. Enabling interaction among different wireless architectures leads to an ideal network support for smart city services; however, it also poses a number of technical and engineering challenges. Our ability to answer such challenges may make the difference between the deployment of expensive yet barely useful communication infrastructures, and that of effective and efficient smart city solutions.

REFERENCES

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: A survey. *Computer Networks*, *38*(4), 393–422. doi:10.1016/S1389-1286(01)00302-4

Ancona, S., Stanica, R., & Fiore, M. (2014). Performance Boundaries of Massive Floating Car Data Offloading. In Proceedings of IEEE/IFIP WONS. doi:10.1109/WONS.2014.6814727

Augé-Blum, I., Boussetta, K., Rivano, H., Stanica, R., & Valois, F. (2012). Capillary Networks: A Novel Networking Paradigm for Urban Environments. In Proceedings of UrbaNE. doi:10.1145/2413236.2413243

Bai, F., Stancil, D. D., & Krishnan, H. (2010). Toward understanding characteristics of dedicated short range communications (DSRC) from a perspective of vehicular network engineers. In *Proceedings of ACM MobiCom*. doi:10.1145/1859995.1860033

Barthel, D., Lampin, L., Augé-Blum, I., & Valois, F. (2012). Exploiting long-range opportunistic links to improve delivery, delay and energy consumption in Wireless Sensor Networks. In *Proceedings of IEEE MASS*.

Bazzi, A., Masini, B. M., & Andrisano, O. (2011). On the Frequent Acquisition of Small Data Through RACH in UMTS for ITS Applications. *IEEE Transactions on Vehicular Technology*, *60*(7), 2914–2926. doi:10.1109/TVT.2011.2160211

Beylot, A.-L., & Laboid, H. (2013). *Vehicular Networks: Models and Algorithms*. Wiley. doi:10.1002/9781118648759

Bluetooth SIG. (2009). *Specifications of the Bluetooth System, Covered Core Package: 3.0 + HS*.

Bluetooth SIG. (2013). *Specifications of the Bluetooth System, Covered Core Package: 4.1*.

Buratti, C. (2010). Performance analysis of IEEE 802.15.4 beacon-enabled mode. *IEEE Transactions on Vehicular Technology*, *59*(4), 2031–2045. doi:10.1109/TVT.2010.2040198

Cabspotting. (2014). Retrieved from http://cabspotting.org/api

Campolo, C., Molinaro, A., & Vinel, A. V. (2011). Understanding the performance of short-lived control broadcast packets in 802.11p/WAVE Vehicular networks. In *Proceedings of IEEE VNC*.

CDM. (2014). *Cisco Data Meter*. Retrieved from http://www.ciscovni.com/data-meter/

Cisco. (2013). *Global Mobile Data Traffic Forecast Update*.

DASH7 Alliance. (2013). *DASH7 Alliance mode draft 02 release: An advanced communication system for wide-area low-power wireless applications and active RFID*.

Di Felice, M., Ghandour, A. J., Artail, H., & Bononi, L. (2012). On the impact of multi-channel technology on safety-message delivery in IEEE 802.11p/1609.4 vehicular networks. In *Proceedings of IEEE ICCCN*.

ETSI TR 101 994-1. (2004). *Short Range Devices (SRD); Technical Characteristics for SRD Equipment using Ultra Wide Band Technology (UWB); Part 1: Communications Applications*.

ETSI TR 103 055-1.1.1. (2011). *Electromagnetic compatibility and Radio spectrum Matters (ERM) - System Reference document (SRdoc): Spectrum Requirements for Short Range Device, Metropolitan Mesh Machine Networks (M3N) and Smart Metering (SM) applications.*

Fehske, A., Richter, F., & Fettweis, G. (2009). Energy efficiency improvements through micro sites in cellular mobile radio networks. In *Proceedings of IEEE GLOBECOM Workshops*. doi:10.1109/GLOCOMW.2009.5360741

Gaillard, G., Barthel, D., Theoleyre, F., & Valois, F. (2014). Service Level Agreements for Wireless Sensor Networks: a WSN Operator's Point of View. In *Proceedings of IEEE/IFIP NOMS*. doi:10.1109/NOMS.2014.6838261

Gallo, L., & Härri, J. (2013). A LTE-Direct Broadcast Mechanism for Periodic Vehicular Safety Communications. In *Proceedings of IEEE VNC*. doi:10.1109/VNC.2013.6737604

Han, B., Hui, P., Kumar, V., Marathe, M., Pei, G., & Srinivasan, A. (2010). Cellular Traffic Offloading through Opportunistic Communications: A Case Study. In *Proceedings of ACM CHANTS*. doi:10.1145/1859934.1859943

Hartenstein, H., & Laberteaux, K. (2008). A tutorial survey on vehicular ad hoc networks. *IEEE Communications Magazine*, *46*(6), 164–171. doi:10.1109/MCOM.2008.4539481

Hartenstein, H., & Laberteaux, K. (2010). *VANET - Vehicular Applications and Inter-Networking Technologies*. Wiley.

Holma, H., & Toskala, A. (2001). *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications*. Wiley.

Hui, J., & Thubert, P. (2011). Compression format for IPv6 datagrams over IEEE 802.15.4-based networks. *RFC 6282*.

Ide, C., Dusza, B., & Wietfeld, C. (2012). Performance Evaluation of V2I-Based Channel Aware Floating Car Data Transmission via LTE. In *Proceedings of IEEE ITSC*. doi:10.1109/ITSC.2012.6338753

IEEE Computer Society. (2003). *Local and Metropolitan Area Networks - Specific Requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). 802.15.4-2003 - IEEE Standard for Information Technology.*

IEEE Computer Society. (2006). *Local and Metropolitan Area Networks - Specific Requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs). 802.15.4 802.15.4-2006 - IEEE Standard for Information technology*.

IEEE Computer Society. (2012). *802.11-2012 - IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems. Local and Metropolitan Area Networks--Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*.

USB Implementers Forum. (2010). *Wireless USB Specification Revision 1.1*.

International Energy Agency. (2012). *Energy Technology Perspectives 2012*. Executive Summary.

ISO/IEC/ECMA. (2013). Near Field Communication Interface and Protocol - 2, 3rd Edition.

ITU. (2014). *ITU-T and Climate Change, Technology Watch Report*.

Kushalnagar, N., Montenegro, G., & Schumacher, C. (2007). IPv6 over low-power wireless personal area networks (6LowPan): Overview, assumptions, problem statement, and goals. *RFC 4919*.

Lee, K., Lee, J., Yi, Y., Rhee, I., & Chong, S. (2010). Mobile Data Offloading: How Much Can Wi-Fi Deliver? In *Proceedings of IEEE/ACM CoNEXT*.

Lin, X., Andrews, J., Ghosh, A., & Ratasuk, R. (2014). An Overview of 3GPP Device-to-Device Proximity Services. *IEEE Communications Magazine*, *52*(4), 40–48. doi:10.1109/MCOM.2014.6807945

Mangel, T., Kosch, T., & Hartenstein, H. (2010). A Comparison of UMTS and LTE for Vehicular Safety Communication at Intersections. In *Proceedings of IEEE VNC*.

Marsan, M., Chiaraviglio, L., Ciullo, D., & Meo, M. (2009). Optimal energy savings in cellular access networks. In *Proceedings of IEEE ICC Workshops*.

Martelli, F., Renda, M. E., Resta, G., & Santi, P. (2012). A measurement-based study of beaconing performance in IEEE 802.11p vehicular networks. In Proceedings of IEEE INFOCOM.

Montenegro, G., Kushalnagar, N., Hui, J., & Culler, D. (2007). Transmission of IPv6 packets over IEEE 802.15.4 networks. *RFC 4944*.

Mouradian, A., Augé-Blum, I., & Valois, F. (2014). RTXP: A Localized Real-Time MAC-Routing Protocol for Wireless Sensor Networks. *Computer Networks*, *67*, 43–59. doi:10.1016/j.comnet.2014.03.020

Moustafa, H., & Zhang, Y. (2009). *Vehicular Networks - Techniques, Standards, and Applications*. Auerbach Publications. doi:10.1201/9781420085723

Mulligan, G. (2007). *The 6lowpan architecture*. EmNets. doi:10.1145/1278972.1278992

Norair, J. P. (2009). Introduction to DASH7 technologies. Retrieved November 30, 2014, from https://dash7.memberclicks.net/assets/PDF/dash7%20wp%20ed1.pdf

Olariu, S., & Weigle, M. (2009). *Vehicular Networks from Theory to Practice*. Chapman Hall/CRC. doi:10.1201/9781420085891

Rosen, D., Mammano, F., & Favout, R. (1970). An electronic route-guidance system for highway vehicles. *IEEE Transactions on Vehicular Technology*, *19*(1), 143–152. doi:10.1109/T-VT.1970.23442

Sohraby, K., Minoli, D., & Znati, T. (2007). *Wireless Sensor Networks: Technology, Protocols, and Applications*. Wiley. doi:10.1002/047011276X

Sommer, C., Schmidt, A., Chen, Y., German, R., Koch, W., & Dressler, F. (2010). On the Feasibility of UMTS-based Traffic Information Systems. *Ad Hoc Networks*, *8*(5), 506–517. doi:10.1016/j.adhoc.2009.12.003

Stanica, R., Fiore, M., & Malandrino, F. (2013). Offloading Floating Car Data. In *Proceedings of IEEE WoWMoM*.

The Copenahagen Wheel. (2014). Retrieved November 30, 2014, from http://senseable.mit.edu/copenhagenwheel

TomTom. (2010). Travel Time Measurements using GSM and GPS Probe Data. In *Proceedings of 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services*. Stockholm, Sweden

Tozlu, S., Senel, M., Mao, W., & Keshavarzian, A. (2012). Wi-Fi enabled sensors for Internet of Things: A practical approach. *IEEE Communications Magazine*, *50*(6), 134–143. doi:10.1109/MCOM.2012.6211498

Tse, D., & Viswanath, P. (2005). *Fundamentals of wireless communication*. Cambridge University Press. doi:10.1017/CBO9780511807213

Tseng, Y.-C., Hsu, C.-S., & Hsieh, T.-Y. (2002). Power-saving protocols for IEEE 802.11-based multi-hop ad hoc networks. In Proceedings of IEEE INFOCOM.

Tunaru, I., Rivano, H., & Valois, F. (2013). WSN-inspired Sleep Protocols for Heterogeneous LTE Networks. In *Proceedings of PE-WASUN*. doi:10.1145/2507248.2507267

United Nations Development Policy and Analysis Division. (2013). *World Economic and Social Survey 2013 - Sustainable Development Challenges*.

United Nations Economic and Social Affairs. (2012). *World Urbanization Prospects. The 2011 Revision*.

Uppoor, S., Trullols-Cruces, O., Fiore, M., & Barcelo-Ordinas, J. M. (2014). Generation and Analysis of a Large-scale Urban Vehicular Mobility Dataset. *IEEE Transactions on Mobile Computing*, *13*(5), 1061–1075. doi:10.1109/TMC.2013.27

Wagner, R. S. (2010). Standards-based wireless sensor networking protocols for spaceflight applications. In *Proceedings of IEEE Aerospace Conference*. doi:10.1109/AERO.2010.5446672

Weyn, M., Ergeerts, G., Wante, L., Vercauteren, C., & Hellinckx, P. (2013). Survey of the DASH7 Alliance protocol for 433 MHz wireless sensor communication. *International Journal of Distributed Sensor Networks*, *2013*, 1–9. doi:10.1155/2013/870430

Wi-Fi Alliance. (2014). *Wi-Fi Peer-to-Peer (P2P) Technical Specifications v1.5*.

Zhang, J., Orlik, P. V., Sahinoglu, Z., Molisch, A. F., & Kinney, P. (2009). UWB Systems for Wireless Sensor Networks. *Proceedings of the IEEE*, *97*(2), 313–331. doi:10.1109/JPROC.2008.2008786

Zhu, H., Li, M., Zhu, Y., & Ni, L. M. (2009). Hero: Online real-time vehicle tracking. *IEEE Transactions on Parallel and Distributed Systems*, *20*(5), 740–752. doi:10.1109/TPDS.2008.147

Zigbee Alliance. (2008). *Zigbee specifications.* ZigBee Document 053474r17.

KEY TERMS AND DEFINITIONS

Cellular Network: Wireless communication system providing pervasive and seamless service to mobile users through a set of base stations, each covering one or more of the cells in which the geographical space is tessellated.

Mobile User: Individual carrying a communication device, which he/she possibly uses while moving.

User Terminal/Equipment: Communication device carried by a mobile user.

Vehicular Network: Wireless communication system composed of vehicles equipped with radio interfaces, and capable of exchanging data among them as well as with the cellular network or other fixed infrastructures.

Wireless Network: Communication network using radio frequency signals to convey data between sources and destinations.

Wireless Sensor Network: Wireless communication system composed of wireless sensors.

Wireless Sensor: Low-cost battery-powered device featuring limited computational and memory resources, as well some sensing and wireless communication capabilities.

Chapter 14

Community Mesh Networks:

Citizens' Participation in the Deployment of Smart Cities

Primavera De Filippi
Université Paris II, France & Harvard, USA

ABSTRACT

Smart cities embed information and communication technologies (ICT) to create interactive milieus that constitute a bridge between the physical and the digital world. In their attempt to improve citizens' quality of life through a more efficient use and sustainability of resources, smart cities might, however, also raise important concerns as regards the privacy and confidentiality of personal data flows. Insofar as the design of a city's telecommunication infrastructure is likely to affect the nature of social dynamics and human interactions, it should, ideally, be achieved through a coordinated, citizen-centric approach combining integrated ICTs with active citizen participation and intelligent physical, digital and informational resource management. This chapter analyzes the case of community mesh networks as an example of grassroots decentralized communication infrastructures, whose architecture design has important implications for the deployment and configuration of smart cities.

INTRODUCTION

Smart cities aim to promote economic development, sustainability, efficiency and greater quality of life (QoL) by using modern digital assets and mobile communication technologies to provide new and innovative services directed towards fulfilling existing and emergent citizens' needs by encouraging participatory action and civil engagement (Caragliu et al., 2009). As such, the deployment of smart cities is a complicated task that involves many multi-faceted issues, comprising questions such as environmental and infrastructural design, community living, and individual mobility. Many different stakeholders are involved in the process of turning a city into a smart city, yet the ultimate beneficiary is (or should be) the citizen. Thus, in order to succeed, this process should, ideally, put citizens at the center of the analysis, considering them an agent rather than a mere target (Nam & Pardo, 2011).

After providing a general overview of the traditional approach to smart city deployment, this chapter analyses the arguments behind the

DOI: 10.4018/978-1-4666-8282-5.ch014

severe criticism which smart cities have recently been subject to. On the one hand, there is growing mistrust towards a purely technologically-driven approach to smart cities, which tend to be treated as an end *per se*, rather than as a means of providing better services and greater QoL for their citizens. Rather than looking at the consequences that technology might have on the social dynamics and perceived interests of people inhabiting the city, the focus is often excessively geared towards improving the technical infrastructure of the city, whose inhabitants are mainly treated as passive users rather than pro-active citizens (Humphries, 2013). On the other hand, the data-driven character of many smart cities – collecting personal information about citizens' habits, lifestyles, and keeping track of their daily behaviors – raises important concerns as regards the privacy and confidentiality of personal data. To the extent that such data is collected, stored and processed by third party operators, citizens lose control over their own personal data, which may be used for secondary purposes without the consent of the data subject (Martinez-Balleste et al., 2013).

In this context, the first run of experiments with smart city deployment (for example, see the various initiatives in Tokyo, London, New York and Barcelona, Singapore's Intelligent Transport System, Dubai's Internet City project, and more recently, South Korea's Ubiquitous-City project turning the city of Incheon into the world's largest and most hi-tech smart city) has shown that a socially-oriented design for urban development is a critical requirement that could lead to dangerous outcomes if not properly implemented. Indeed, if the needs of citizens are not properly taken into account in the development of smart cities, the outcome is likely to be an environment that actually alienates citizens who do not recognize or understand (and sometimes simply do not agree with) the new value propositions that are being offered to them through the smart city infrastructure. Given the growing impact that technology is having on our everyday life, there is today a growing need to implement smart cities through a more grassroots, citizen-centric approach.

Emerging technologies may provide a solution to this need by facilitating the development of tools for promoting social inclusion and participation in the design of tomorrow's smart cities. This chapter focuses specifically on the use of mesh networking technology as an example of grassroots decentralized communication infrastructures that might play an important role in the deployment of smart cities. The objective is to understand whether, and how, can citizens become active participants in improving their own city's infrastructure, without giving up their individual autonomy or foregoing their rights to privacy and data protection. Ultimately, the success and long-term sustainability of smart cities might depend more on their ability to deploy new and innovative instruments for the empowerment of communities, rather than on the deployment of sophisticated technologies which are deployed and controlled by third party operators, and subsequently imposed in a top-down fashion to the city's inhabitants, without giving them the opportunity to participate in the design and management of these technologies. If the goal is, ultimately, to improve the quality of citizens' lives, it is not enough to supply more personalized and customized services. It is also important – if not essential – to provide citizens with new opportunities for social interactions within the urban environment, along with a higher degree of freedom and autonomy.

BACKGROUND

Smart cities embed information and communication technologies (ICT) to create interactive environments that constitute a bridge between the physical and the digital world. Technological advances are pushing towards digital convergence. As different media can now communicate with one another, an increasing number of devices and applications are becoming more and more integrated and dependent upon each other. Digital technologies are slowly finding a place in our everyday objects and devices, increasingly blurring the line between the physical and digital world.

The deployment of high speed broadband allows for expeditious communications and facilitates the global dissemination of large amounts of information, in virtually no time. Wireless networks have brought connectivity to a whole new level by enabling mobile devices to remain connected to one another, even when in transit. This allows for the establishment of dynamic network connections which can be easily shared amongst multiple devices at virtually no cost. Thanks to the proliferation of smart phones and other mobile devices, individuals are always connected and constantly communicate – be it consciously or unconsciously – with the digital world.

We have now entered a new era of ubiquitous and pervasive computing. Computers, laptops, tablets, smart phones and other digital devices are increasingly connected (and interconnected) in such a way that we are able to communicate and exchange information with one another (Want & Pering, 2005). In the most industrialized countries, it is now difficult for people to communicate in such a way that does not involve any modern telecommunication network or digital device. People are increasingly connected to each other through their own devices – which are, in turn, connected to many other people or devices.

With the advent of cloud computing, individuals are now capable of accessing their own data (including their personal data) regardless of their physical location and without being tied to any specific device. Smart (connected) devices are becoming a *de facto* standard, or simply a necessity in such an information-driven society, where most of the utility or use value is no longer derived from the use of the device itself, but rather from its ability to connect with the networked digital world. Connectivity has, ultimately, become an essential prerequisite to the information infrastructure of any modern city.

In the age of ubiquitous computing, smart devices become an integral – and yet often invisible – part of the world we live in (Steventon & Wright, 2006). With the Internet of Things (IoT), the Internet extends its reach to the physical world. Connected devices are turned into sensors that automatically collect data and record changes in users' behaviors, sometimes without them even being aware of it. Individuals are surrounded by sensors of all kinds: personal computers, smartphones and other integrated devices (including objects such as kettles or fridges, but also more personal accessories such as clothing, bracelets, and watches) are now equipped with Internet connection, positioning tracking systems, accelerometers and even RFID readers. These devices are constantly tracking and recording information about the world surrounding them, in order to learn more about users' activities and behaviors, as well as their specific preferences and tastes. With the recent growth in popularity of the 'quantified self' community – individuals interested in monitoring or self-tracking themselves by means of wearable sensors and devices – the amount of data available on the Internet is now greater than ever (Swan, 2012).

These large quantities of data are being continuously aggregated, processed and analyzed in order to produce new information, with a growing level of accuracy. In the context of smart cities, this often leads to more customized or personalized services that ultimately contribute to increasing citizens' quality of life (Brooks, 2013).

To date, intelligent sensors have already been deployed in a variety of cities, in order to support and facilitate the management of daily tasks in a costless and much more efficient way. For instance, the City of Westminster has installed sensors in parking spaces to help drivers find parking in nearby streets. In Barcelona, waste containers have been equipped with sensors that communicate the container's state to waste collectors, so as to promote a more efficient and dynamic route management system for waste collectors (who can focus exclusively on the containers that are full, while ignoring those that do not need to be collected). Again in Barcelona, sensors have been deployed in certain areas of the city to modify the intensity of street lights, not only according to meteorological conditions, but also depending on the density of people in public squares.

While this might seem trivial at first, the combination of these small enhancements into a more integrated ecosystem might lead to the establishment of a much more sophisticated system, made up of a multiplicity of interconnected parts interacting with one another dynamically so as to adjust their operations according to the information they receive from the other system components. As more and more facets of our world are turning into data, the urban environment itself becomes part of the global information system, eventually leading to the creation of hybrid environments – "phygital" spaces merging the physical world with the digital world by means of electronic artifacts powered by the computational power of the network to which they are connected (Bazzanella et al., 2013).

Infrastructure Design and Its Social Implications in the Context of Smart Cities

Connectivity, ubiquity and interactivity are key elements to the design of a city's socio-technical infrastructure. Modern telecommunication infrastructures make it possible for a municipality to manage large complex environments and to better communicate with its citizens. Intelligent sensors deployed in a networked environment allow for a more efficient use of resources, whose usage can be more easily monitored and administered from afar. As digital technologies are incorporated into most communication infrastructures, the city becomes more responsive to current and emerging citizens' needs. Indeed, not only does the entanglement of digital technologies within the urban space enable a more responsive reaction to disruption (e.g. power outage, floods, traffic or congestion, etc.), it also provides the means of collecting and processing large amounts of data from present and past situations, so as to anticipate real-world problems or events.

Smart cities constitute a platform for creating new services that rely on collective intelligence to offer innovative solutions to citizens' needs. By turning the urban space into a more dynamic and interactive environment, the IoT represents an essential step towards establishing a more modern and efficient city management system. The challenge raised by rapid technological changes and emerging user needs requires the creation of an intelligent environment made up of a network of integrated devices communicating with one another, so as to provide citizens with highly customized and personalized services, before they even feel or express the need for the same.

All this, however, comes at a cost. To the extent that these communication infrastructures determine the nature of social dynamics and human interactions, their benefits cannot be properly understood without accounting for the possible repercussions they might have on citizens' social and civic life. In this regard, the architectural design of these infrastructures must be carefully scrutinized when analyzing the impact they have on civil liberties and democratic values. This is all the more relevant when it comes down to the privacy of end-users, which is currently being jeopardized by the systematic collection of personal data or information that we are witnessing today on the Internet. In any such data-driven society, preserving the privacy and confidentiality of personal data flows becomes a crucial issue, which might lead to a series of unpleasant consequences if it is not properly accounted for. In order to fully exploit the potential of smart cities in accordance with the fundamental rights of end-users, the design of their telecommunication infrastructure needs to be carefully taken into account, both at their conception and during the overall deployment of the urban environment.

CENTRALIZED AND DECENTRALIZED NETWORK INFRASTRUCTURES

The design of any given infrastructure shapes or influences the social dynamics that might occur on the same structure, i.e. it affects the ways in which people interact with and through the structure. In the context of communication infrastructures, the design determines the nature of information communicated throughout the network (e.g. voice, video, data, etc.), the way such information is passed on to the public (one-to-one, one-to-many, many-to-many), and the way different information agents can interact with each other (centralized, hierarchical structures vs. distributed, symmetrical organizations). Different typologies of network architectures might, therefore, encourage or discourage different types of communications and information flows.

Centralized network infrastructures are likely to promote the deployment of hierarchical communication systems, whereby individuals have to connect to one or more established servers in order to gain access to a particular network. This is the model adopted by standard TV and radio broadcasting (one-to-many), traditional telephone communication systems (where all communications must pass through at least one telecommunications operator) and most Internet service providers implemented thus far. In spite of their differences in function and scope, all of these infrastructures share an important commonality: they all rely on a centralized entity in charge of regulating access to the network and managing the information flow travelling on that network.

Decentralized network infrastructures rely instead on a distributed system of communication based on a more symmetrical (non-hierarchical) model. As opposed to the former client-server approach to network communications, decentralized architectures rely on a network of peers that act both as clients and servers, depending on the circumstances. Every node in the network is equally important (although the model might allow for supernodes, which have priority over the other nodes) and they all contribute to managing access and routing traffic through the network of peers.

This model is inspired by the advent of distributed applications designed to allocate tasks and workloads amongst a network of peers, first popularized with the deployment of P2P file sharing applications. Yet the model inspired people to experiment with decentralized structures in many other areas of human interaction – from software development with the open source movement (Healy & Schussman, 2003), to artistic production with Creative Commons licenses (Lessig, 2004; Benkler & Nissenbaum, 2006), and, more recently, the implementation of decentralized monetary systems, such as Bitcoin and other derivative crypto-currencies (Nakamoto, 2008).

P2P systems challenge most of the dominant practices associated with centralized environments. Firstly, they eliminate the need to establish a hierarchical structure by establishing a network of peers which are all assumed to be equal. Secondly, they eliminate the need for intermediaries, thus bypassing the traditional bottlenecks characteristic of centralized production processes. Thirdly, they promote an alternative model of production which relies on sharing and cooperation as preconditions for the viability and long-term sustainability of the system. This latter point brings along a wide set of social implications due to the human dynamics associated with peer collaboration. In this sense, P2P systems also represent a political choice (Bauwens, 2005), to the extent that they rely on specific social and relational ties between all participants involved in decentralized production, which ultimately promotes a specific organizational and political structure.

As illustrated by Raymond's topical paper "*The Cathedral and the Bazaar*" (1999), as opposed to traditional models of production based on a top-down approach to decision-making, where only a few people are in charge of, and responsible for the implementation of a project according to specific rules and constraints (e.g. the *Cathedral* model), the *Bazaar* is characterized by a much more grass-roots and bottom-up approach, which distinguishes itself to the extent that the production processes are not dictated by any single entity, but rather by the project itself. In other words, a community of dispersed individuals contributes to the project not because of a specific commitment they have made, but merely because of their shared view and commitment to achieving a common objective. The system of norms regulating this latter type of production is therefore extremely informal, often based on the principles of *actocracy* (i.e. the first to act is the one to rule), collective agreement and implicit consensus (O'Mahony & Ferraro, 2007). Everyone willing to participate can contribute to the project, and, by doing so, becomes an integral part of the decision-making process.

Although the Bazaar governance model has thus far mostly been tested in the context of on-line communities concerned with the production of digital, non-rival goods (software, content, data, etc.), several attempts have been made to export this particular system of governance to other fields of endeavor. The following sections illustrate the privacy-deficit that is characteristic of a large number of smart city environments whose design is grounded in a centralized architecture. Subsequently it analyzes the case of community mesh networks as an example of how the mechanisms of decentralized governance and P2P production can be implemented at the level of technical communications infrastructure. This is an excellent example of innovation and privacy working hand in hand, as privacy is embedded into the design, operation, and management of the communication infrastructure, across the entire information lifecycle.

THE ISSUE: PRIVACY AND DATA PROTECTION

Security, privacy and confidentiality play a key role in the design of smart city infrastructures. Yet preserving individuals' privacy and autonomy in the context of smart cities is an arduous challenge today, in particular in light of current efforts towards generalized surveillance by both corporate and governmental entities (Bauman & Lyon, 2012).

While they involve the deployment of a large number of sensors distributed throughout the whole city, the information management systems adopted by the vast majority of smart cities are generally highly centralized. Huge amounts of data (from air temperature to air contamination and carbon dioxide levels, from electricity usage to gas, humidity and dew point, from current street traffic to available parking spaces, etc.) are collected and aggregated into large centralized data centers, where they are subsequently processed using sophisticated algorithm and big data analysis techniques to identify the current concerns or foresee the upcoming ones, and perhaps figure out the causes or solutions to the various issues affecting the city.

Most of these initiatives have, however, been launched with a view to increasing the overall efficiency of public services, without paying too much attention to their implication on the privacy of individuals, eventually leading to a state of ubiquitous surveillance that is similar (or worse) than the one currently found on the Internet.

On the Internet, mass surveillance has become a critical issue, especially after Snowden's revelations concerning the U.S. National Security Agency's (NSA) operations, which gave a symptomatic example of the intrusive powers that governmental bodies are exerting in the digital world. Increasingly sophisticated technologies (such as sniffers, spoofers, keyloggers, or Deep Packet Inspection techniques) are currently being employed by both private parties and public authorities to monitor online communications.

While such practices have been performed for many years over the Internet, they are now also emerging in the physical world. In fact, they have been greatly amplified with the advent of smart cities and the IoT, which combine urban management with pervasive computing, ubiquitous networks and distributed sensors connected to each other in order to provide real-time information about the world around us.

Today, as more and more devices are connected to the Internet, surveillance is progressively extending to every aspect of our daily life. Our digital footprints are getting bigger and bigger (Madden, 2007), as everywhere we go, everything we do, and everything we interact with – either online or offline – is collecting data about us. A striking example is the rapid deployment of surveillance cameras (CCTVs), which initially were only deployed in the context of specific locations such as shopping malls or business complexes, but are progressively taking over the public landscape of many metropolises around the world (such as London, Hong Kong, Singapore, etc.). The cameras no longer operate on their own, but are more and more integrated with other sensors and control systems such as fire detectors, alarms, and anomaly detectors as well as traffic control systems, crowd flow monitoring, forecasting stations, and so forth. As more and more connected sensors permeate the urban territory, they might progressively lead toward effective command and control systems (such as those deployed temporarily during large-scale demonstrations or sports events) being permanently deployed at city-level, providing a better picture of citizens' activities within the urban landscape. This trend can already be observed in several smart cities, such as the Domain Awareness Center[1] in Oakland, California, or Rio de Janeiro's Intelligent Operations Center[2] in collaboration with IBM, which proposes to implement a comprehensive dashboard for the whole city in order to optimize resources and assist public authorities in preserving public order and safety.

But citizens are also being monitored by other types of sensors located not only throughout the territory, but also within their own hands. Increasingly, citizens are being tracked by communicating smart-devices: computers, tablets, smart-phones and other interactive devices which constantly collect data (including personal data) from their surrounding environment, aggregate them into a central database and process them with a view to better understanding the current state of affairs, or even anticipating potential problems and risks.

However, despite the significant costs it might entail in terms of privacy and data protection, data collection and analysis on such a massive scale can hardly be avoided. Indeed, smart cities *need* to collect information about their citizens in order to better understand their characteristics, behaviors, and needs, so as to provide them with a more customized service that is likely to increase the city's standard quality of life. More and more people are thus willing to give up their privacy for the sake of obtaining a more customized or personalized service. They explicitly or implicitly accept that they are being physically tracked by their own smartphones, cameras, RFID chips, as well as having their online activities monitored by cookies, beacons, or other tracking devices, so as to ultimately benefit from new and innovative services that rely on their own personal data in order to better satisfy their most inherent needs. This, of course, brings up the difficult question of where we should draw the line between what constitutes a personalized service that is actually geared towards the interests of end-users, and what should instead be regarded as a form of target advertising geared towards the interests of advertisers. Most importantly, is such a distinction still useful, or are the two previously distinct approaches actually merging into each other within this new integrated environment?

The problem is that – thus far – virtually every attempt to deploy smart cities has been undertaken by either corporate or governmental institutions. While the former are for the most part driven by economic incentives, the latter are torn between the desire to provide a public utility service and the need to ensure public order and national security. And yet, in spite of their different motivations, both are likely to favor a model that promotes a regime of generalized surveillance, which is naturally likely to impinge upon the privacy of individual citizens.

In order to be successful in the long-run, any initiative aimed at providing new and innovative services to guide or support citizens in their daily interactions with the urban environment should give citizens a say on the manner and the extent to which service providers are entitled to collect, use and reuse personal data. Most importantly, in order to remain in line with the provisions of the new European data protection regulation[3], data collection and analysis should only be done with the explicit and informed consent of the data subject (Article 6) and citizens should be given the choice to opt in or out of these initiatives (Article 4) subject to full disclosure as regards the policies for information retrieval and information sharing procedures (Article 15). Yet most of the smart cities which have been implemented so far fall short of some of these basic requirements (Allwinkle & Cruickshank, 2011).

Most of the problems inherent to privacy and data protection could be resolved if efforts towards smart city deployment were not exclusively run by public authorities (driven by public policy and political goals) and private actors (whose interests are limited to short-term economic returns), but mostly by grassroots communities and civil organizations who actually have an incentive to promote the greater good (Townsend, 2013). Indeed, if the aim of smart cities is to improve citizens' QoL through greater efficiency and sustainability, the deployment of a smart city should not be dictated by any economic, corporate or governmental interest, but rather by the desire to further the interests of actual citizens. For this to be successful, there is a need for a more bottom-up and less corporate-led implementation of smart cities, relying on a grassroots, citizen-centric approach, combining integrated ICTs with active citizen participation and intelligent physical, digital and informational resource management (Caragliu et al., 2009). This is especially true in the context of communication infrastructures which are one of the main vehicles for citizens to engage and participate in political, social and cultural life. While it is fundamental that municipalities provide the underlying technical telecommunications infrastructure, and it is useful that private companies be allowed to compete to provide a more added-value service, today citizens must also realize the important role they might play in shaping the ground for grassroots innovation in the context of ICTs (Townsend, 2013).

PROPOSED SOLUTION: COMMUNITY MESH NETWORKS

In light of the growing interest (and need) toward deploying modern ICTs and the lower infrastructure costs for wireless communications, decentralized approaches to networked communications are acquiring more and more momentum, both within civil society and elsewhere. Thus, in addition to top-down institutional projects aimed at the development of smart cities, citizens are progressively organizing themselves into communities seeking to establish an interface which can connect the urban environment to the digital world, in ways which are more autonomous, self-sustainable and privacy-compliant than their commercial or municipal counterparts.

In this regard, community mesh networks (CMN) are an interesting example of grassroots decentralized communication infrastructures, whose architecture design has important implications on the deployment and configuration of smart cities, as well as on the way communities form and operate. A variety of initiatives have been developed thus far to support the deployment of decentralized mesh networks, allowing for a variety of devices such as mobile phones, computers, and other wireless apparatuses to communicate directly with one another without passing through a centralized server or authority.

Ad-hoc mesh networks are decentralized network infrastructures that rely on a distributed and loosely coordinated network of peers contributing their own resources to the network, so as to provide Internet connectivity to a specific community without relying on any pre-existing network infrastructure. They are also more robust than traditional centralized networks, in that they can dynamically adapt to changes in their surroundings and automatically reconfigure themselves according to the current availability of resources: if a new node appears, it will be automatically connected to the rest of the network, without the need for any additional configuration; if a node fails or disappears, the network will automatically reconfigure itself in order to route around it.

By means of a decentralized network infrastructure, mesh networks promote a more democratic, communitarian and participatory approach to network governance. As opposed to centralized network infrastructures which are generally owned and managed by third parties (be they private or public institutions) CMN are operated by the community and for the community. They are autonomous citizen-centric communication infrastructures, designed to preserve the autonomy and fundamental rights of individuals by making every individual user responsible for the provision and redistribution of network connectivity, but also in charge of routing the traffic throughout the network.

Privacy and Security

Mesh networks might potentially provide a solution to the privacy concerns raised by centralized smart city infrastructures by promoting an open, decentralized, peer-to-peer approach to network infrastructure and connectivity.

Thus far, most CMN have been deployed as "open networks" promoting the principles of network neutrality and preserving individual rights such as privacy and freedom of expression. Indeed, the decentralized character of mesh networks ensures that there is no single entity that controls the network: this means that there are no intermediaries or gatekeepers that might censor, filter, or perhaps even disclose information to corporate or governmental entities. As such, mesh networking represents a way of preserving the confidentiality of online communications. Given the lack of a central authority that regulates access to the network, it is extremely difficult for anyone to assess the real identity of users connected to these networks.

Besides, most of the open-source equipment that is used in the context of many mesh networks enables citizens to remain in control of their own data. To the extent that they have full control over their own devices, users' rights to privacy are less likely to be infringed upon, as users are free to determine the manner and the extent to which their devices can collect personal data and communicate it to other connected devices. Citizens can assemble their own devices, deploy their own mesh networking kit, install their own software and manage their own data through it. They can even decide to share their personal data with their closest friends or, more broadly, with a larger community, but only according to the conditions that they have individually chosen.

In the context of smart cities, this means that citizens can enjoy the benefits of more customized and personalized services which are tuned to and automatically adapt to evolving users' needs, without having to renounce their privacy or let go of their right to data protection.

Greater privacy does not, however, necessarily lead to greater security. While citizens can more effectively control the collection and/or use of their personal data, it remains nonetheless important to ensure that such data remains safe from unauthorized access by third parties. As every device connected to an open network is potentially insecure, malicious users might try and hack into the system to get hold of sensitive data, alter the device's functionalities, or even just corrupt the system by introducing a virus or malware. Besides, even if they are not (directly) connected to the global Internet network, it is of course still possible for malicious third parties who are locally connected to a domestic mesh network to monitor the traffic transiting through the network. The technology cannot, by itself, be used to conceal one's identity or provide strong security for network traffic. It is, in fact, the "open" design of many community mesh networks that makes them inherently insecure: if anyone is entitled to join the network either as a client or a relay node transferring packets throughout the network, then anyone locally connected to that network is also capable of intercepting (or sniffing) these packets. Unless users employ end-to-end encryption, the content of all messages and communication can easily be monitored by third parties. In fact, even with encryption it is still possible to collect metadata (i.e. who sent what to whom) unless one uses an overlay network such as Tor or Cjdns to obfuscate the source and/or destination of communications[4].

In this sense, mesh networks do not provide any more protection against surveillance by either governmental or corporate entities than the global Internet does. They do, however, contribute to changing the rules of the game and the corresponding power dynamics by making users more autonomous, informed and aware, and by giving them the ability to control the extent to which data is being collected and the manner in which such data is transmitted through the network. To the extent that the network is not deployed by any third party, it is for the community itself to ultimately decide the manner in which the network should effectively be designed and implemented.

Citizen-Centric Technologies

What is really revolutionary about mesh networking is not the novel use of technology, but rather the fact that it provides a means for people to organize themselves into communities and share resources. Although originally designed to overcome crisis situations (Portmann & Pirzada, 2008) or to escape from the oppressive control of totalitarian regimes (Hasan at al., 2013), mesh networks have thus far been deployed by several communities and civil society organizations as a means to experiment with new models of governance: an inclusive form of governance based on participation and collaboration among peers.

By analogy with the concept of commons-based peer production (Benkler, 2006), CMNs constitute an attempt at transposing the concept of open source cooperation in the physical world. By virtue of their decentralized character, these networks require a communitarian and participatory approach to Internet communication. The creation of a mesh network is ultimately a collective process which requires every member of the community to participate in producing a common platform of communication, whose utility is generally greater than the sum of its parts. Individual users contribute their own resources to the overall operations of the network, and the greater the number of users, the greater the value of the network as a whole.

Indeed, given that CMNs are generally deployed to satisfy the needs of a particular community, community members have an incentive to provide resources to the network so as to maximize the benefits they can derive from it, both individually and collectively. Although each individual network user might have personal (and sometimes conflicting) interests, all have an interest in contributing to the network insofar as they can reap benefits from it. This is exactly the kind of spontaneous collaboration that feeds into the system and encourages the public to provide more and more resources to distributed peer-to-peer networks (see e.g. Golle et al., 2001; Ranganathan et al., 2003; Antoniadis et al., 2004).

An interesting application of CMN with reference to smart cities is illustrated by the Smart Citizen project, an initiative launched by Tomas Diez (director of Fab Lab Barcelona). It is aimed at empowering citizens to achieve a better quality of life by supporting and promoting more citizen participation in better understanding and improving the city they live in. The Smart Citizen kit is an Arduino-operated device with a set of low-cost modular open hardware sensors that can be used to capture, process and analyze real-time environmental data (such as air quality, temperature, sound or humidity). By creating a mesh network of such sensors, data collected by a variety of citizens can be shared on the Smart Citizen platform and subsequently aggregated into a common database from which new knowledge or indicators can be extracted. The goal is, ultimately, to allow citizens to co-operate towards constructing a more sustainable environment through more efficient urban development.

Citizens can thus play a key role in the design of smart cities by providing the means of assessing the effectivity of urban policies geared towards improving community, civic and social life in the city. Yet as opposed to the traditional approach to smart city deployment (where a large number of sensors are installed throughout the city to collect data about citizens without them even being aware of it), with the Smart Citizen project it is individuals themselves who are collecting data about their own environment, by relying exclusively on their own devices. In this sense, citizens are no longer regarded as mere data-subjects, but rather assume a more active role as data-providers. They contribute – either implicitly or explicitly – to the urban environment by interacting with specific applications which have been deployed to collect data directly from the individuals who are the most concerned with a particular issue, and the most eager to benefit from a service that is more suited to the needs of their particular community. Data might either refer to the urban environment (for example, see Fillthathole.org.uk, where citizens can report holes in the roads so that the city can fix them; WideNoise, an application that uses the IPhone microphone to measure decibels at a specific location) or to the individual themselves (for example, see Asthmapolis, which developed a tool for asthma patients allowing them to monitor and publicly disclose their medical activities, in the hope that public health agencies will eventually make use of the data collected to improve their health). Because they are actually in control of their own devices, and given that they know exactly what kind of data they are sharing with whom, individuals are likely to be more willing to share information (even personal information) with each other, if they believe they can either individually benefit from it, or at least contribute to the greater good. Most importantly, because they are not dependent on any third party, citizens are better equipped to satisfy their own needs by their own means, without having to compromise between privacy and utility. With mesh networking, community members can reclaim control over their own means of communication, and consequently decide for themselves which underlying functionalities and technical features they want to implement. Ideally, this would lead to the deployment of smart cities run by smart citizens, driven by the desire to build new and innovative structures capable of providing highly customized and personalized services which promote democratic values and preserve civil liberties and fundamental rights.

FUTURE RESEARCH DIRECTIONS

Of course, only a minority of people are currently capable of deploying a mesh network. Most mesh networks were initiated by a few tech-savvy communities with a strong commitment to openness, inclusiveness and transparency (De Filippi & Tréguer, 2014). Today, however, most users are passively using the network and do not understand the underlying complexity that is required to manage it. Yet as Wikipedia has shown, the power of the digital era is that the work of a few can actually affect the reality of many (Kittur et al., 2007). All the system needs is a small number of experts capable of setting up the basic infrastructure so that others can subsequently benefit from it and, ideally, contribute their own resources to the system.

Mesh networks were initially difficult to deploy. Since every node acts both as a client and relay node, users need to set up their own server and configure it to use the appropriate routing protocol before they can use the network. Configuration is challenging for inexperienced users, and can be very time-consuming even for the most experienced ones.

Today, the situation has changed drastically. A few years ago, the Commotion Wireless[5] project from the New America Foundation's Open Technology Institute began working on the "Internet in a suitcase" project: an Open Source toolkit that can be readily installed in a variety of low-cost, off-the-shelf devices for anyone to set up a mesh network without any technical knowledge. The project, which was originally motivated by the need to provide a secure and reliable platform to prevent authoritarian governments from controlling or blocking dissident or activist communications (King, 2011), has now become one of the most popular tools for mesh network deployment around the globe (for more details, see http://www.commotionwireless.net). Similar tools are also being developed by other communities, including MeshNet (https://projectmeshnet.org), NodeWatcher (http://dev.wlan-si.net/wiki/Nodewatcher), or the Serval Project in Australia (http://www.servalproject.org). The goal is, ultimately, to allow anyone to deploy the necessary software infrastructure to enable direct communications between a variety of user devices. Some communities even have gone one step further by providing pre-installed, pre-configured hardware devices, such as the Open-Mesh routers from MIT that only need to be plugged into an electrical outlet (and, ideally, to an Internet connection) to provide connectivity on-the-fly (see http://open-mesh.com for more details).

But mesh networking technologies are also progressively being deployed in our everyday devices. Just a few months ago, Open Garden released FireChat (https://opengarden.com/firechat), a proprietary end-user application making use of Apple's new bluetooth multi-peer mesh networking capabilities provided by iOS 7 to enable anyone with an iPhone or IPad to set up a modular ad-hoc mesh network. It only took a few weeks for a similar functionality to be enabled on Android phones, so that both iOS and Android users can now communicate on the same mesh network. As more and more of these applications get deployed into standard end-user devices, we might soon witness the emergence of a more grassroots and citizen-centric approach to smart cities, with the deployment of an IoT that ultimately relies on grassroots applications of mesh networking technologies.

The flip-side is, however, that grassroots community networks can only subsist insofar as there is someone willing to contribute to the network. As opposed to software, which, once produced, remains operational and available to all (even if the community no longer assigns any resources to further develop it), WCNs cannot operate without a constant provision of resources to sustain the infrastructure. In order to ensure the long-term sustainability of the network and maximize the benefits that they can derive from the network (both individually and collectively), users need to provide the system with resources and work together to resolve any network failures that might occur over time (as a result of a router breakdown or a displaced radio antenna, for example). Although mesh networks might allow for the establishment of supernodes (which have priority over other nodes by virtue of their greater bandwidth, for instance), all users eventually contribute to increasing the overall network bandwidth. This is especially true in the context of ad-hoc mesh networks based on dynamic routing protocols, where the efficiency of the network ultimately depends on the number of users who accept, at any given moment, to operate as relay nodes.

One important question in this regard relates to the incentive mechanisms that might be employed to encourage citizens to contribute their own resources to the deployment of grassroots smart city environments. Beyond the ideological values related to privacy and autonomy, additional benefits must be extracted for such an alternative approach to enter into the mainstream.

A number of WMN are currently experimenting with innovative mechanisms to incentivize participation and encourage user contributions to the network. A particularly interesting solution is CommunityCoin, an initiative proposed by the Guifi[6] community network. CommunityCoin is a crypto-currency based on the same technology as Bitcoin, which has been specifically designed for network communities. It features a mechanism of rewards based on community members' contribution to and participation in the overall operation of the network. This currency can, however, only be used for the internal community workaround: users contributing their resources to the network will be able to spend the CommunityCoins they receive in order to buy second-hand hardware from another community member, for example. The goal is, ultimately, to incentivize members to work for the community (installing new nodes, creating new services, etc.) and make the community network self-sustainable.

Of course, mesh networking only represents one small (albeit critical) part of the overall smart city infrastructure. Technology can (and should) also be deployed to elaborate and deploy innovative systems of governance, encouraging citizens to be much more responsible, and perhaps more responsive to their own needs. A truly emancipatory technology should not only provide the means for citizens to become more independent and autonomous within their own city, but also to exercise greater control and oversight over the municipality. A potential solution to the latter is the MuniBit initiative, launched by Zachary Caceres from the Startup Cities Institute[7]. It relies on distributed cryptoledgers (the underlying technology of Bitcoin) to improve transparency of government finances in the developing world, by inviting citizens to actively participate in the verification and execution of all financial transactions stemming from local authorities (in order to preclude fraud or corruption), as well as to eventually become shareholders in their local government, and contribute to political decisions through a transparent digital process (Swanson, 2014). Here, the technology once again incorporates the political goal of encouraging the establishment of strong and cohesive communities capable of self-organizing in order to fulfill their own needs, by their own means.

CONCLUSION

The deployment of smart cities and the IoT are providing considerable advantages to many citizens eager to experience new social connections and interactions within the urban environment. Yet by reason of their centralized character and the extensive degree of data collection they entail, the current approach to smart-city deployment is often highly intrusive and might substantially hinder citizens' rights to privacy and data protection.

Are citizens thus expected to trade-off their privacy for the sake of greater comfort or efficiency? Quite the contrary. The need to align innovation policies for smart city deployment with better urban development and greater citizen empowerment requires us to reconsider the role of citizens as the central focus of smart city development. Indeed, beyond the initial deployment of smart devices, the development and long-term sustainability of smart cities requires us to develop innovative technologies and infrastructures capable of promoting participation and social inclusion in the cities of tomorrow. Yet in order to do so, the general approach to smart city deployment must integrate the social component to the technical component.

By deploying mesh networks, citizens can set up their own smart-city environments, connecting several devices together in a decentralized fashion within a peer-to-peer network. These devices can interact with a multitude of devices connected to one another, so as to coordinate themselves without the need for a centralized authority.

Ideally, this would lead to the establishment of an open and decentralized network infrastructure (composed of a variety of citizen-owned sensors or devices). It would empower citizens with innovative interactive and customized services so as to increase their overall quality of life, while remaining in compliance with fundamental privacy and data protection rights. Indeed, to the extent that citizens are in charge of setting up and managing the networks, they are likely to be deployed in a way which better respects the privacy and autonomy of users, who can benefit from the same advantages and functionalities provided by traditional smart cities environments without the costs of centralized control.

Accordingly, by relying on community mesh networks as opposed to third party infrastructures, cities can be "smart" while also respecting their citizens' intelligence. Paradigmatically, the creation of independent network infrastructures regulated through innovative models of governance becomes a key prerequisite for the involvement and participation of smart citizens in smart city deployment.

REFERENCES

Allwinkle, S., & Cruickshank, P. (2011). Creating smart-er cities: An overview. *Journal of Urban Technology*, *18*(2), 1–16. doi:10.1080/10630732.2011.601103

Antoniadis, P., Courcoubetis, C., & Mason, R. (2004). Comparing economic incentives in peer-to-peer networks. *Computer Networks*, *46*(1), 133–146. doi:10.1016/j.comnet.2004.03.021

Bauman, Z., & Lyon, D. (2013). *Liquid Surveillance: A Conversation*. Cambridge: Polity Press.

Bauwens, M. (2005). *The political economy of peer production*. Retrieved from http://www.ctheory.net/articles.aspx?id=499

Bazzanella, L., Roccasalva, G., & Valenti, S. (2013). *Phigital Public Space Approach: A Case Study in Volpiano*. Retrieved from http://www.mifav.uniroma2.it/inevent/events/pcst_sce_2013/docs/I_5.pdf. 2013.

Benkler, Y. (2006). *The Wealth of Networks: How Social Production Transforms Markets and Freedom. London*. New Haven: Yale University Press.

Benkler, Y., & Nissenbaum, H. (2006). Commons-based Peer Production and Virtue*. *Journal of Political Philosophy*, *14*(4), 394–419. doi:10.1111/j.1467-9760.2006.00235.x

Brooks, D. (2013). *The Philosophy of Data*. Retrieved from http://www.nytimes.com/2013/02/05/opinion/brooks-the-philosophy-of-data.html?_r=0

Caragliu, A., Del Bo, C., & Nijkamp, P. (2009). Smart cities in Europe. In *Proceedings of Central European Conference in Regional Science*.

De Filippi, P., & Tréguer, F. (2014). Expanding the Internet Commons: The Subversive Potential of Wireless Community Networks, *Journal of Peer Production*.

Golle, P., Leyton-Brown, K., Mironov, I., & Lillibridge, M. (2001). Incentives for sharing in peer-to-peer networks. *Electronic Commerce*, *2232*, 75–87.

Hasan, S., Ben-David, Y., Fanti, G., Brewer, E., & Shenker, S. (2013). Building Dissent Networks: Towards Effective Countermeasures against Large-Scale Communications Blackouts. In *Proceedings of Workshop on Free and Open Communications on the Internet*.

Healy, K., & Schussman, A. (2003). *The ecology of open-source software development*. Retrieved November, 30, 2014, from http://kieranhealy.org/files/drafts/oss-activity.pdf

Humphries, C. (2013). The too-smart city. Retrieved November, 30, 2014 from http://www.bostonglobe.com/ideas/2013/05/18/the-too-smart-city/q87J17qCLwrN90amZ5CoLI/story.html

King, R. (2011). *Building a Subversive Grassroots Network. Spectrum*. IEEE.

Kittur, A., Chi, E., Pendleton, B. A., Suh, B., & Mytkowicz, T. (2007). Power of the few vs. wisdom of the crowd: Wikipedia and the rise of the bourgeoisie. *World Wide Web (Bussum)*, *1*(2), 19.

Lessig, L. (2004). *Free culture: How big media uses technology and the law to lock down culture and control creativity*. New York, NY: The Penguin Press.

Madden, M. (2007). *Digital Footprints: Online identity management and search in the age of transparency*. Washington, DC: Pew Internet & American Life Project.

Martinez-Balleste, A., Perez-Martinez, P. A., & Solanas, A. (2013). The Pursuit of Citizens' Privacy: A Privacy-Aware Smart City is Possible. *IEEE Communications Magazine*, *51*(6), 136–141. doi:10.1109/MCOM.2013.6525606

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. Retrieved November, 30, 2014 from https://bitcoin.org/bitcoin.pdf

Nam, T., & Pardo, T. A. (2011). Smart City as Urban Innovation: Focusing on Management, Policy, and Context. In *Proceedings of International Conference on Theory and Practice of Electronic Governance*. doi:10.1145/2072069.2072100

O'Mahony, S., & Ferraro, F. (2007). The emergence of governance in an open source community. *Academy of Management Journal*, *50*(5), 1079–1106. doi:10.5465/AMJ.2007.27169153

Portmann, M., & Pirzada, A. A. (2008). Wireless mesh networks for public safety and crisis management applications. *IEEE Internet Computing*, *2*(1), 18–25. doi:10.1109/MIC.2008.25

Ranganathan, K., Ripeanu, M., Sarin, A., & Foster, I. (2003). To share or not to share: An analysis of incentives to contribute in collaborative file sharing environments. In *Proceedings of Workshop on Economics of Peer-to-Peer Systems*.

Raymond, E. (1999). The cathedral and the bazaar. *Knowledge, Technology & Policy*, *12*(3), 23–49. doi:10.1007/s12130-999-1026-0

Steventon, A., & Wright, S. (Eds.). (2006). *Intelligent Spaces: The Application of Pervasive ICT*. London: Springer-Verlag. doi:10.1007/978-1-84628-429-8

Swan, M. (2012). Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0. *Journal of Sensor and Actuator Networks*, *1*(3), 217–253. doi:10.3390/jsan1030217

Swanson, T. (2014). *Great chain of numbers: a Guide to Smart Contracts, Smart Property and Trustless Asset Management*. Amazon Digital Services, Inc.

Townsend, A. M. (2013). *Smart cities: big data, civic hackers, and the quest for a new utopia*. New York, NY: WW Norton & Company.

Want, R., & Pering, T. (2005). System challenges for ubiquitous & pervasive computing. In *Proceedings of ACM International conference on Software engineering* (pp. 9-14).

KEY TERMS AND DEFINITIONS

Cloud Computing: Cloud computing refers to a distributed infrastructure that is made of a collection of interconnected computers, whose resources are pooled together into a virtual machine that maintains and manages itself. As opposed to other distributed architectures, the particularity of cloud computing is that the architecture is completely independent from the physical infrastructure it relies upon. This allows for extreme flexibility, as resources can be dynamically added or removed according to actual needs.

Information or Data Privacy: The right to privacy refers to the ability of an individual or group to seclude themselves, or information about themselves, and thereby express themselves selectively. Specifically, in line with the definition provided by the European Charter of Fundamental Rights, the right to privacy is to be distinguished from the fundamental right to data protection, which is more concerned with the manner in which personal data is being collected and processed.

Information or Data Security: In computing, security is commonly described as the conjunction of three major properties: information confidentiality (the fact that only authorized entities can access a piece of information), integrity (the fact that a piece of information cannot be unduly modified) and availability (the fact that authorized entities are not prevented from accessing a piece of information). In order to ensure these properties, various types of properties and technical tools may be used, such as authentication, authorization, non-repudiability, encryption, cryptographic signature, etc.

Mesh Networks: Mesh networks are decentralized network infrastructures that rely on a distributed and loosely coordinated network of peers contributing their own resources to the network so as to provide Internet connectivity to a specific community without relying on any pre-existing network infrastructure. They are more robust than traditional centralized networks, in that they can dynamically adapt to changes in their surroundings and automatically reconfigure themselves according to the current availability of resources.

Peer-to-Peer Networks: Peer-to-peer networks are decentralized network infrastructures that rely instead on a distributed system of communication based on a more symmetrical (non-hierarchical) model. As opposed to the traditional client-server approach to network communications, peer-to-peer network architectures rely on a network of peers that act both as clients and servers, depending on the circumstances.

Smart Cities: Smart cities embed information and communication technologies (ICT) to create interactive environments that constitute a bridge between the physical and the digital world. People interact with these environments by means of physical artifacts (sensors, smart devices, etc) powered by the computational power of the network to which they are connected. In their attempt to increase the quality of life through a more efficient use and sustainability of resources, smart cities raise, however, important concerns as regards the privacy and confidentiality of personal data flows.

ENDNOTES

1 The Domain Awareness Center (DAC) is a planned surveillance hub which aims to integrate public and private cameras and sensors all over the City of Oakland into one $10.9M mass surveillance system. For more information, see http://oaklandwiki.org/domain_awareness_center.

2 IBM Intelligent Operations Center for Smarter Cities provides an executive dashboard to help city leaders gain insight into all aspects of the city. For more details, see http://www.ibm.com/software/products/en/intelligent-operations-center.

3 The European Commission plans to unify data protection within the European Union (EU) with a single law, the General Data Protection Regulation (GDPR). A proposal for a regulation was released on 25 January 2012. Subsequently numerous amendments have been proposed in the European Parliament and the Council of Ministers. The EU's European Council aims for adoption in late 2014 and the regulation is planned to take effect after a transition period of two years.

4 TOR (The Onion Router) and CJDNS are two publicly accessible overlay networks that provide anonymity to their users by encrypting and routing their requests through a number of peer nodes to disguise the real origin of the traffic.

5 Commotion Wireless is an open-source wireless mesh network for electronic communication. The project was developed by the Open Technology Institute, and development included a $2 million grant from the United States Department of State in 2011 for use as a mobile ad hoc network (MANET). For more details, see https://commotionwireless.net/.

6 Guifi.net is a free, open telecommunications community network which is self-organized: all nodes of the network are contributed by individuals, companies or institutions that supply their own resources to provide infrastructure and content that might not otherwise be accessible.

7 Startup Cities Institute (SCI) is a non-profit research organization that studies the use of startup communities for legal and political reform. Startup Cities are small and highly autonomous jurisdictions established within pre-existing nations. They can be used to create inclusive economic growth, combat corruption and insecurity, and to test public policy innovations in public services, transparency, and environmental stewardship. SCI is a project of Universidad Francisco Marroquín in Guatemala City.

Section 4

Data and Decision-Making in Smart Cities

Chapter 15
Crowdsensing in Smart Cities:
Technical Challenges, Open Issues, and Emerging Solution Guidelines

Paolo Bellavista
Università di Bologna, Italy

Antonio Corradi
Università di Bologna, Italy

Giuseppe Cardone
Università di Bologna, Italy

Luca Foschini
Università di Bologna, Italy

Raffaele Ianniello
Università di Bologna, Italy

ABSTRACT

The widespread availability of smartphones with on-board sensors has recently enabled the possibility of harvesting large quantities of monitoring data in urban areas, thus enabling so-called crowdsensing solutions, which make it possible to achieve very large-scale and fine-grained sensing by exploiting all personal resources and mobile activities in Smart Cities. In fact, the information gathered from people, systems, and things, including both social and technical data, is one of the most valuable resources available to a city's stakeholders, but its huge volume makes its integration and processing, especially in a real-time and scalable manner, very difficult. This chapter presents and discusses currently available crowdsensing and participatory solutions. After presenting the current state-of-the-art crowdsensing management infrastructures, by carefully considering the related and primary design guidelines/choices and implementation issues/opportunities, it provides an in-depth presentation of the related work in the field. Moreover, it presents some novel experimental results collected in the ParticipAct Crowdsensing Living Lab testbed, an ongoing experiment at the University of Bologna that involves 150 students for one year in a very large-scale crowdsensing campaign.

DOI: 10.4018/978-1-4666-8282-5.ch015

INTRODUCTION

Thanks to the recent advances in Information Communication Technologies (ICTs), for the first time more smartphones than feature phones were shipped in 2013, thus marking a trend whereby the former will permanently outnumber the latter. The explosive and widespread diffusion of smartphones enables data availability and gathering, provided by sensors, such as accelerometers, barometers, cameras and microphones. This information can be densely available and harvested in urban areas, preparing a large ground for crowdsensing, in the sense of allowing large-scale and fine-grained sensing by exploiting all personal resources and people's mobile activities/collaborations.

At the same time, Smarter Cities themselves can also make several resources and data available to be managed and harnessed safely, sustainably, cost-effectively and efficiently to achieve positive and measurable economic and societal advantages. Information gathered from people, systems and things, including both social and technical data, is one of the most valuable resources available to the city's stakeholders, but its potentially enormous volume makes its integration and processing difficult, especially in a real-time and scalable manner.

The ability to harness the power of the above collective intelligence (even if inaccurate) to self-organize the spontaneous collaboration of citizen groups with other people to achieve, through their collective action, a common goal with a tangible effect also on the physical material world, namely, e-Participation and e-Inclusion, is still largely unexplored (Fogg, 2009). We consider it essential to fill this gap by proposing a new class of pervasive services, called participatory services, to emphasize their fundamental feature of providing people with the innovative opportunity to participate and act collectively. In short, the main objective of participatory services is to close the loop between immaterial and material world scenarios in the pervasive cyber-physical system of a Smarter City, going in the direction of facilitating positive behaviors by preventing dangerous situations and of enabling smarter e-Governance with a high participation of interested citizens, thus fostering an increased sense of belonging. The final goal is to enable new models for the development of the consciousness/environmental awareness on the part of the citizen as a consumer and user of the quality and environmental impact of goods and services that they expect and use in their Smarter Cities.

To become really effective technologies, crowdsensing and participatory services still have to face a number of challenges that can be considered from either a main social perspective or a more technically-oriented one. From a more social point of view, there are many duties involved in people participation: the identification of people willing to participate in crowdsensing campaigns, how to keep them involved (e.g. by providing attractive crowdsensing and participatory services, entertainment and rewards), and how to foster their participation with active collaboration actions in some data collection campaigns, for instance that require people to operate at a specific location (e.g. taking a picture of a monument, tagging a place etc.). From a technical point of view, it is important to balance sensing accuracy and user resource utilization to avoid making the crowdsensing process cumbersome to users, to process incoming data, to clean up corrupted entries, and to store information in a format that allows fast space-time queries. The boundary between social and technical challenges is not clear cut: for example, the technical problem of minimizing the global resource overhead by entrusting a minimal subset of users in a crowdsensing campaign requires the analysis of large datasets to extract a proper geo-social/preferences profile, in order for example to identify and infer which users are most likely to successfully harvest the required data.

Because crowdsensing and all above topics are not only articulated but also deeply interconnected, there are as yet no clean and easy to follow strategies in this area; most contributions seem to search for an ad-hoc solution without solving the problem of elaborating both a model and a supporting architecture that can be generally applied and tuned to provide a specific solution. Hence, starting from the core assumption that only a deep and broad knowledge of existing efforts can help to distill clear design guidelines and pave the way to the development of new classes of crowdsensing and participatory services, this chapter aims to gather together current efforts to provide an original and holistic view of the existing proposals.

In more detail, the chapter will consist of three main parts and will be organized as follows: the first part will be more tutorial, sketching our design model to classify crowdsensing and participatory services. We will focus on the requirements of participatory service platforms, including not only sensing support at mobile devices, but also stressing the role of controlling all policies and driving the whole scenario through a Smart City management supervisor, which is in charge of strategies to orientate the participating behavior and also to analyze the currently available crowdsensing information. This includes the definition of coordinated crowdsensing actions, the delivery of specific crowdsensing tasks to execute to the final users, the management of incentives to give to final users (including monetary ones, gamification etc.), and data post-processing, mining, and maintenance capabilities. In the second part, we will use the proposed design guidelines to analyze existing crowdsensing and participatory infrastructure research proposals. To assess the technical soundness of our design guidelines, several solutions will be analyzed and categorized spanning all main functions of crowdsensing and participatory platforms. We show that most existing solutions are usually too specific, while only a few recent proposals are able to truly support different application areas (from energy to transport, from e-health to e-Participation, and many more) through common sets of reusable sensing and socio-technical management functions. Finally, the third part claims the need for real crowdsensing and participatory platforms, and for large and long-running experiments. Following this direction, we conclude by detailing the ParticipAct crowdsensing living lab testbed, an ongoing experiment at the University of Bologna, which involves 150 students for one year in crowdsensing campaigns that can passively access smartphone sensors and require active collaboration. We will show some preliminary but relevant results that confirm that ParticipAct makes it possible to easily and quickly test and devise new participatory strategies by collecting a large amount of data from different sources connected with a Smart City experiment.

CROWDSENSING FOR SMART CITIES: AN ORIGINAL TAXONOMY OF MAIN DESIGN GUIDELINES AND FUNCTIONS

Recent disruptive technologies – such as location-based services, the Internet of Things, and multimodal interfaces – are the basis of new distributed services that in the near future will use cities as development and deployment platforms. Worldwide, large cities are extremely important in social development: 50% of the world population lives in cities, the top 100 urban centers account for 25% of the global Gross Domestic Product, and by 2050 the urban population will comprise of almost 6.4 billion people; socially, the tightly knit collaborative community of cities promotes the free flow of ideas, leading to exponentially greater innovation. Since cities account for more than 75% of global energy consumption and are responsible for 80% of all greenhouse gases, they have to be considered the central focus for driving worldwide sustainability. The high population density and the very large number of different interconnected issues make effective city management a challenging task, but at the same time future Smart Cities provide countless opportunities to foster collaboration among people by keeping them in the loop.

Several significant government and industrial research projects are currently underway and confirm the impact that smart technologies may have on society in the near future. The European Digital Agenda has funded many projects, such as European Digital Cities, InfoCities, IntelCity roadmap and EUROCITIES, to promote smart urban services. The EU has also funded FuturICT, a long-lasting 10-year initiative that seeks to "understand and manage complex, global, socially interactive systems, with a focus on sustainability and resilience". Around the world, the government of South Korea is building the Songdo Business District, a green low-carbon area that aims to become the first full-scale realization of a smart city.

Many corporate initiatives are also on the way. One of the most significant is the IBM Smarter Planet project that promotes the deployment of several "smarter systems" to improve social progress, from smart grids and traffic managers to water management and cheaper/safer healthcare. A similar effort led by Intel aims at using London as a testbed where users and the existing city infrastructure are exploited to improve the city's efficiency, for instance to manage traffic flows, predict extreme weather conditions, and monitor water supplies.

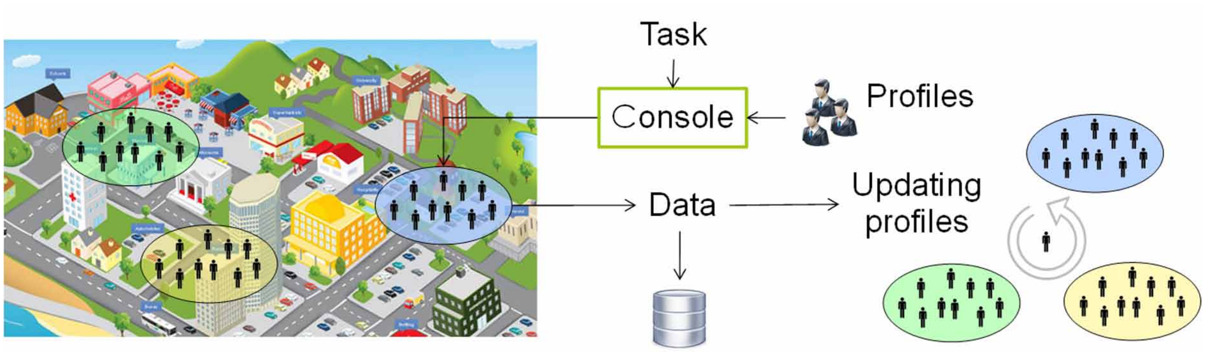
Although communication trends and developments – spanning from the advent of instant messaging and Voice over IP (VoIP) to Web 2.0, social networks and beyond – have enabled and disclosed new forms of interaction, the whole information management cycle is today mostly focused on the virtual, immaterial, Internet computing world. People use their devices to communicate with their friends, to sense the surrounding physical environment (e.g. to take photos/videos, sample a change of physical position through onboard GPS etc.), and to upload significant amounts of user generated information about it to the Internet. Socially-enabled services automatically connect and facilitate the delivery of interesting information to people sharing common interests and goals. At the same time, one of the main functions required to enable truly intelligent next generation Smart Cities is sensing the physical world. The typical Smart Cities sensing scenario nowadays is it to equip city areas that have to be monitored with many fixed sensors, and to deploy several (often overlapping) fixed sensing infrastructures covering the whole city and typically requiring high installation and maintenance costs.

Crowdsensing aims to overcome the above issues and exploit the power of collective (though imprecise) intelligence to self-organize the spontaneous and impromptu collaboration of large groups of people, who participate with other people and opportunistically exploit available physical devices and machines in their vicinity to achieve a common sensing of the material physical world. In other words, while crowdsourcing aims to leverage collective intelligence to solve complex problems by splitting them into smaller tasks executed by the crowd, crowdsensing splits the responsibility of harvesting information (typically urban monitoring) among the crowd in order to enable potential collaborative corrective/management actions in the Smart City world.

Crowdsensing is a great example of a new class of pervasive services, which we call participatory, to highlight their crucial and groundbreaking characteristic of providing people with the chance to participate and act collectively; in brief, the main aim of participatory services, and of crowdsensing as an important example and building block, is to close the loop between the immaterial and material worlds in next generation large scale pervasive computing Smart City scenarios. Indeed, crowdsensing changes the usual Smart City sensing scenario shown in Figure 1 by dynamically involving and coordinating several users in sensing campaigns, and by exploiting modern smartphones

Figure 1. Sensing based on fixed infrastructure connecting wired sensors in the city area

Figure 2. Crowdsensing based on opportunistic involvement of volunteers moving in the city area



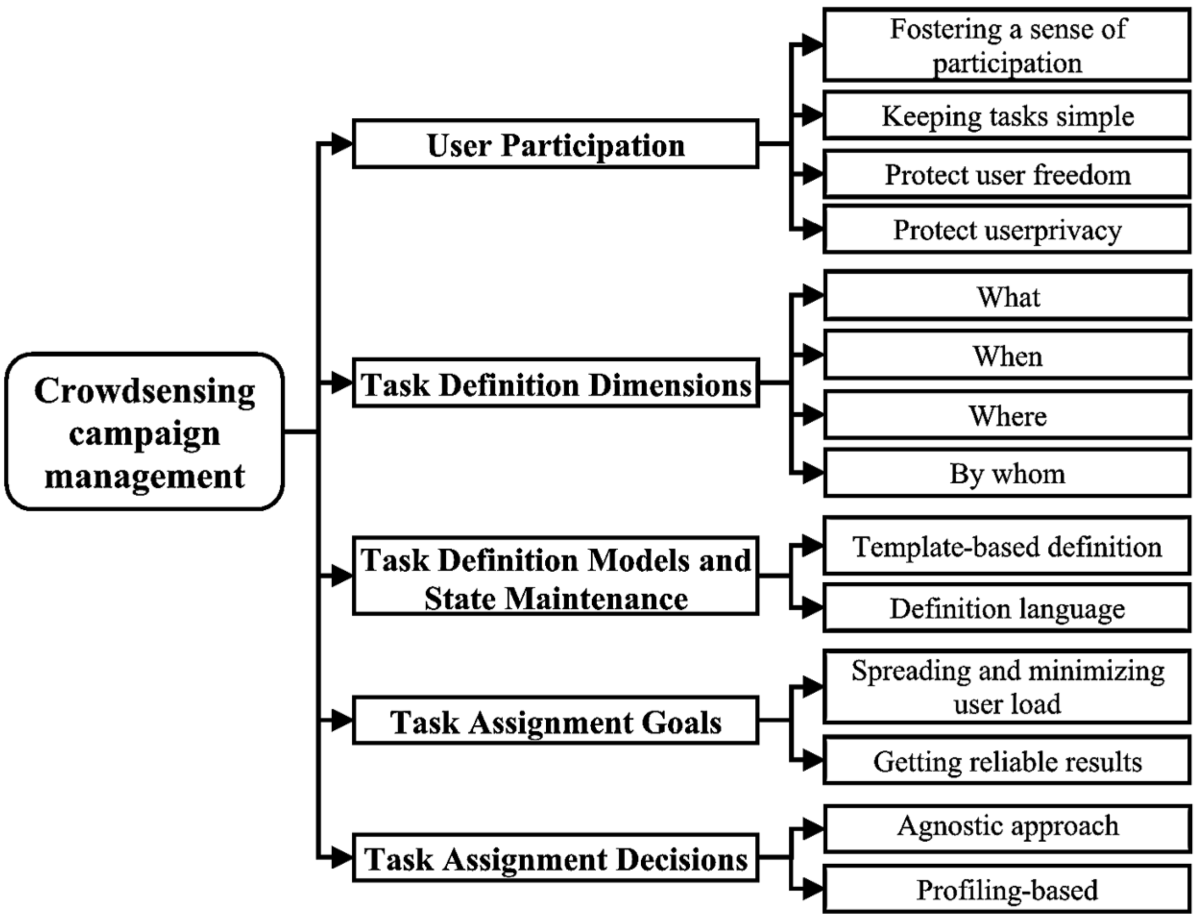
as a means to reach and opportunistically involve mobile volunteers willing to complete required sensing actions (see Figure 2).

The new scenario calls for supporting various new features that include: *management of crowdsensing campaigns* (typically called Tasks to be delivered and accepted by volunteers); efficient and smartphone-enabled *sensing of data*; and accurate *data post-processing and mining* for profiling users and city areas (along both space and time dimensions) to evaluate the assignment of tasks to users for future crowdsensing campaigns and analyze crowdsensing performance. The remainder of this section provides more details on all these main functions; in particular, for each dimension, we will introduce possible taxonomy directions so as to better clarify how each dimension affects the design and the decisions of the crowdsensing infrastructure.

Crowdsensing Campaign Management

The goal of crowdsensing campaign management (see Figure 3) is to coordinate a (possibly large) group of people to gather a given – possibly complex – type of data. Examples of possible crowdsensing campaigns are collecting geolocation data, asking for a photo of a given target, and harvesting geotagged noise level.

Figure 3. The proposed taxonomy for categorizing crowdsensing solutions according to classes of campaign management



User Participation

Employing both devices and users to collect data from the real world poses significant social and technical challenges. From a social point of view, it is important to motivate user participation, for example by providing useful crowdsensing-based services, handing out incentives, and *fostering a sense of participation* in a community (Fogg, 1998; Fogg, 2002). It is likewise important to avoid overloading users with duties over the limit of what they are willing to contribute for crowdsensing by *keeping single tasks simple* to avoid discouraging them. Moreover, crowdsensing has similarities with traditional crowdsourcing platforms, such as Amazon Mechanical Turk (AMT), that act as mediators between task clients, usually called workers, and providers: the introduction of such platforms has driven specific research efforts that aim at optimizing crowdsourcing resources by also introducing some form of (monetary, but also other) *incentive* (Ipeirotis, 2010). For example, Bernstein, Karger, Miller and Brandt (2012) propose a statistical model and an algorithm to pre-recruit and pay workers to minimize task execution time on AMT. Finally, all crowdsensing systems should *protect user freedom* by allowing them to accept/refuse to join a data collection campaign, and also guarantee *user privacy* by letting users stop/resume any crowdsensing task at any time or by informing the user of the data that the system is going to send, and giving them the opportunity to veto some or all it. Another possible option is to maintain the anonymity of the sender.

Task Definition Dimensions

Task definition dimensions should allow crowdsensing managers to specify what, when, where, and by whom data should be collected. *What* defines all fine-grained sensing actions and what desired data to collect. *When* reports time bounds such as the availability window of the task to be accepted and completed therein, the task duration, and the duration of the sensing to consider the task completed. *Where* allows for the specification of geographical locations for task execution in two different ways: geonotification associates the task to one or more geographical areas that must be traversed by a user to receive the notification of the task availability; geoexecution, meanwhile, associates it to one or more geographical areas and allows data to be collected only by users located therein. Finally, *by whom* is the set of people available for crowdsensing that have been tentatively assigned to the task and should accept or refuse to execute it.

Task Definition Models and State Maintenance

Another important aspect of task definition is the definition model used to represent these requirements; definition models differ in expressiveness, memorization cost, and processing overheads, but broadly speaking it is possible to distinguish two main classes. On the one hand, the majority of the existing systems employ a *template-based definition model* that allows for the composing and configuring of all main task parameters; typically these systems come with a Web interface integrating a Geographical Information System (GIS) with drop-down menus and drag-and-drop support to pinpoint tasks over the map and ease all needed configuration operations. On the other hand, there are *task definition languages* that offer a fully-fledged high-level programming language that makes it possible to add some intelligence to the task and to add (simple) decision points enforced by the crowdsensing system that manages the whole task lifecycle. In any case, since crowdsensing platforms are complex distributed systems that involve several distributed entities, possibly intermittently disconnected due to wireless medium faults and idiosyncrasies, an essential requirement is to keep the task state synchronized between clients running on user devices and the fixed infrastructure hosting the final results of the completed campaigns.

Task Assignment Goal

In its simplest formulation, crowdsensing is a two-step process: the assignment of sensing tasks to users and the wait for results after the completion of assignments. A more refined approach, taken by new emerging crowdsensing platforms, is to exploit information about potential participants and their mobile execution context (people's geographical location, frequency of visits to an area, commuting times etc.) to better and more effectively tailor the task assignment process. In other words, modern crowdsensing systems should focus on *spreading and minimizing user load*, assigning crowdsensing tasks only to people that are likely to execute them and sharing the workload fairly among participating users according to different possible policies. Another important aspect of task assignment is *getting reliable results* by including the possibility of replicating the same sensing task to multiple users, and then by challenging either them or other users to discover incorrect data deliberately given by malicious users.

Task Assignment Decision

Finally, focusing on the task *assignment decision* aspect, it is important to distinguish *profiling-*

based solutions from more agnostic approaches. A profiling-based solution can be based on past completion history using spatio-temporal user traces, reputation, and so forth. During spatio-temporal analysis an elaboration of different complexities can be carried out. A simple analysis can focus on frequency of presence in a specific place or area. To make this kind of evaluation it is, of course, necessary to define areas in which to apply the search. A more complex evaluation is where points of interest are extracted from a specific person GPS trace using clustering algorithms like DBSCAN (Ester, Kriegel, Sander, & Xu, 1996). An agnostic might choose users randomly or based only on very recent history, for example selecting only recent users that have been in the area where the task is to be executed. Selection can also consider temporal intervals where users frequent a place related to the task to further improve the probability of success.

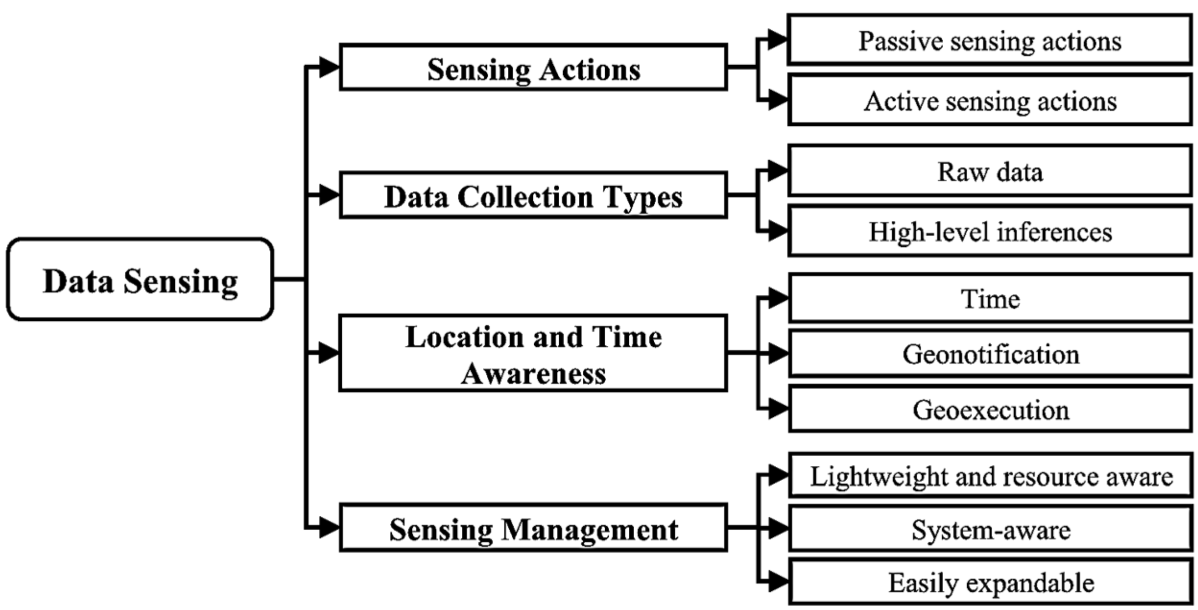
Data Sensing

Data sensing (see Figure 4) includes all the management and data processing functions needed to collect data available via smartphone sensing platforms and to automatically de-activate those sensing activities that depend on the current time and location of participants.

Sensing Actions

Sensing actions unambiguously identify the desired data to be collected. Existing crowdsensing systems usually support both data that can be automatically collected without user intervention by smartphone sensors, called *passive sensing actions*, and data that requires active user contribution to be collected, defined *active sensing actions*. Examples of passive sensing actions include gathering accelerometers, Wi-Fi scans,

Figure 4. The proposed taxonomy for categorizing crowdsensing solutions according to primary data sensing options



ambient noise level, and GPS position, while active sensing ones comprise taking a photo, answering a survey, and tagging a place. Of course it is possible to have a system that supports the definition of tasks that combine both types of sensing actions, such as associating a picture to the place where it was taken.

Data Collection Types

As regards data collection types, for either type of sensing action, we define two different types of collected data: *raw data* are directly gathered by a physical/virtual sensor offered directly by the sensor; *high-level inferences*, meanwhile, are obtained by employing multiple sensors and by melding them using signal processing and machine learning support to automatically collect high-level inferences about user activities. In other words, sensing should promote the availability of high-level inferences that means that while accessing sensors on a smartphone is a relatively trivial process, providing high-level inferences is a much more valuable feature. For instance, processing raw accelerometer and GPS samples, it is possible to identify current user physical activities, such as user walking, running, standing, and so forth. Recognizing current user activities and calculating high-level inferences are very fruitful topics in crowdsensing, as confirmed by the large amount of work in these areas.

Location and Time Awareness

An important aspect in data sensing is notifying the availability of a new task and then activating the required sensing action. As introduced above, tasks may have *time* (when) and *location* attributes, both *geonotification* and *geoexecution*. Typically, crowdsensing platforms tend to push the task to the chosen user smartphone as soon as it is created, and to keep it in a dormant hidden state until it becomes available (it is in the availability window). As for geonotification, tasks are kept in a hidden state (even if they are already available from a temporal perspective) until the smartphone verifies that it is geographically positioned within the geonotification area. Hence, the notification is triggered only when the user enters an area and this is useful in those scenarios where we want user opinions about a place they have travelled through or stopped at. Geoexecution, meanwhile, periodically checks the current location of the smartphone, stopping data collection if the smartphone is outside the areas designed for data collection and resuming when it is within their bounds. This feature allows for the restriction of the sensing activity to a precise geographical area and is very useful, especially for enabling the smart management of big events where the city manager is typically interested in monitoring the situation of specific hot areas only.

Sensing Management

The sensing management component on the smartphone client side plays a pivotal role in crowdsensing because it is in charge of accessing all the sensors available on smartphones and collecting and processing their output. Sensing is a power-hungry process that should be carefully driven in order to avoid any negative impact on user experience, as suggested by the minimal intrusion principle. In order to be effective and viable for the final users involved in long-term crowdsensing campaigns, sensing should be *lightweight and resource-aware*; in fact, it is important to minimize resource consumption by including low-level optimizations (e.g. sensors duty cycling) to reduce overheads and to limit the impact on local resource usage (CPU, memory, communications, bandwidth etc.) so as to both reduce impact on battery lifetime and limit the detrimental effects on device performance. As such, sensing management should go to great lengths to minimize resource consumption. At the same time, sensing systems should be *system-aware*: the sensing system coexists with the Operating System and several other applications with whom it competes for access to not-shareable resources; as such, the sensing system should resolve conflicts and promote a non-intrusive approach. For example, when there are in-/out-bound phone calls, sensing management should automatically disable any sensing access to microphones. Finally, the sensing management core should be *easily extendible* to allow fast integration of new classifiers and algorithms to infer high-level information from raw sensed data making it easy for developers to wire their new data processing code.

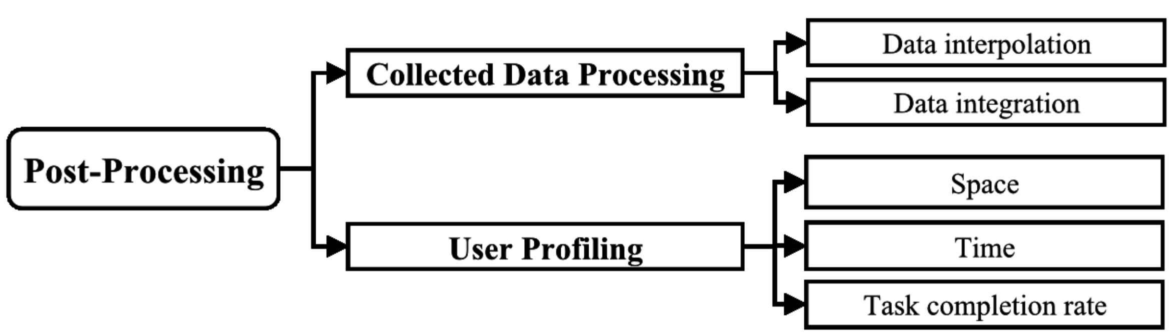
Post-Processing

Crowdsensing systems must support the complete data management workflow, from its collection to transmission, processing, mining and result provisioning. The post-processing of collected data and task results (see Figure 5) is crucial for quickly processing stored data and reducing as much as possible the delay from data reception to data availability, and processing the information needed for task assignment.

Collected Data Processing

Focusing on the post-processing of data, we distinguish two main functions. The first one is *data interpolation,* which improves data collection by filling in missing data points that can be inferred with sufficient accuracy. A notable case of data improved by interpolation is geolocation data. For instance, current position on Android devices is available via Google geolocation Application Programming Interfaces (APIs) that dynamically switch between different techniques to infer user position, from using GPS to using Wi-Fi MAC addresses and searching for them in a geographical database, to exploiting cell tower IDs to estimate position, which in turn causes location accuracy to range from a few meters when the GPS is turned on, to thousands of meters when using the cell tower ID only. Interpolation allows for the detection of geolocation data outliers whose accuracy is significantly worse than that of temporally close data points, and substitutes them with a linear interpolation of the more accurate data points. The second function is *data integration*, which processes data after the interpolation step and aims at aggregating data in time and space. For instance, time aggregation could be achieved by collapsing all data of any type collected in the same 5 minute window in a single row to enable the time-based indexing of all sensed data. Space aggregation, meanwhile, is the operation that links every piece of data to the location it was sensed, thus creating a geographical view of sensed data, and storing it in a Geographic Information System database (GIS) to enable the fast execution of geographical queries.

Figure 5. The proposed taxonomy for categorizing crowdsensing solutions according to primary post-processing options



User Profiling

Profiling users makes it possible to identify those who might find a task easier than others, and thus are more likely to accept and complete it. This is especially evident for tasks that should be executed in a specific area: it makes sense to assign them to users who are likely to visit that area, because the same task will be easier for them than for users that rarely or never pass by the area. Building upon the time-based and space-based views generated by collected data processing functions, and considering also the acceptance and success rate of the tasks by the users, profiling aims at building rich profiles to promptly identify users that are more likely to successfully execute a task based on their recorded behavior. We distinguish three main types of profiles based on space, time and task completion rate. *Space* profiling is geographical-centric in the sense that it tracks people moving in a specific area, but it also exploits time information, such as the time of day, to shape user history in that area. Space profiling makes it possible, for instance, to query the frequency with which a user has been active in that area in a specific period of time during the day. *Time* profiling, meanwhile, is complementary because it enables, given a certain time of the day, the querying of hot areas frequented by many users. *Task completion rate* keeps track of both per-user completed tasks and the reliability of the user, namely reputation, based on the quality of returned sensed data. Each of these three profiles are very important in enabling intelligent task assignment policies that, for instance, could take into account the frequency with which a user has been into a certain place, its reputation, and its past load and reputation, to increase crowdsensing campaign effectiveness also by involving a limited number of users.

RELATED WORK

Here we use the previously introduced taxonomy to survey the primary state-of-the-art research work in literature by classifying the existing proposals according to the main attributes used for Smart Cities Crowdsensing. For the sake of clarity, we voluntarily focused more on crowdsensing platforms that address all crowdsensing-related aspects because, although several efforts on data sensing only are already available (and some good surveys are available as well: Lane et al., 2010), we believe that there is the need for a more integrated and holistic approach to crowdsensing as an entire process. In addition, we have decided to organize the related work according to the three primary directions of our original taxonomy, namely crowdsensing campaign management, data sensing and post-processing, and to report, in each of the associated subsections, all the solutions that address the related aspects; therefore, the same solution and proposal might be referred to multiple times in different subsections depending on the relevant features it offers and implements.

Crowdsensing Campaign Management

Medusa is a system that uses a high-level domain-specific programming language called MedScript to define sensing tasks and workflows that are promoted with monetary incentives to encourage user participation; it employs a distributed system that coordinates the execution of these tasks between smartphones and a cluster hosted in the cloud (Ra, Liu, La Porta, & Govindan, 2012). It provides abstractions, called stages, for modeling intermediate steps in (sub-components of) a crowdsensing task, and for controlling flow between stages (called connectors). Unlike most programming languages, it provides the programmer language-level constructs for incorporating workers into the sensing workflow. The Medusa runtime is architected as a partitioned system with a cloud component and a smartphone component. By using MedScript it is possible to organize incentives, sensing tasks, and processing tasks in high-level workflows while the underlying Medusa framework hides the resulting complexities and takes care of task coordination, worker management, incentive assignment, and result collection. In other words, the Medusa framework specifically and primarily deals with innovative ways to specify algorithms for crowdsensing tasks. Medusa is also a system focused on maintaining a degree of privacy. All data that leaves the phone must be approved by the human worker. The worker is presented with a preview of the data and is given an opportunity to opt-in to the submission. Optionally, at this stage, the requestor may specify a link to a privacy policy that describes how workers' submissions will be used. If a worker chooses to opt out of the upload, the upload stage fails.

Ohmage is a healthcare-oriented system that exploits smartphones to collect information about users (Ramanathan et al., 2012). A trigger is attached to a single action and each individual participant can modify her trigger settings on her mobile device.

Matador is a crowdsensing software framework that focuses on context awareness to optimize task assignment while minimizing battery consumption (Carreras et al., 2013). In particular, Matador assumes that a task is defined by a geographical and a temporal dimension, and should be assigned to users who are within a given geographical area in a given temporal window. The type of actions associated with a task can vary depending on the application scenario: an action can be a request for a multimedia content (e.g. a request to take a photo and to record a video or sound clip), participation in a questionnaire (e.g. to answer a question and to express a free-text opinion). Each task is further characterized by its context, which specifies when such a task should be triggered to the user or by the user's device. In other words, the resulting system aims at delivering the right tasks to the right people in the right circumstances. The notion of context awareness in the delivery and execution of tasks characterizes the approach and makes it possible to: i) maximize conditions for user participation by presenting only tasks relevant to given users, with minimal user intervention; and ii) minimize the consumption of mobile device resources, specifically batteries, thus preserving normal operations. The context can be defined along multiple dimensions such as geography (e.g. within a circular area, along a street), time (e.g. on given dates, during given hours), demographics (e.g. age, gender), user activity (e.g. movement speed, no active calls) and so on.

USense is a middleware for community sensing that strongly decouples users collecting monitoring information and managers requiring crowdsensing data: managers specify which kind of data they need and USense matches them with people meeting the requirements (Agarwal et al., 2013). The basic blueprint of a crowdsensing application consists of a sensing agent running on a smartphone, while a back-end application (server) aggregates results and provides infrastructure services. This platform has cloud-based coordination middleware to jointly harness the sensing potential of smartphones and harvest the necessary sensor data recorded by sensors. The players form an ecosystem (i.e. a producer-consumer ecosystem of sensors and applications, respectively) with a few controlling stakeholders administering the flow of information between the producers and the consumers based on certain objectives. The coordination middleware receives high-level queries of the type: "Give me pollution maps of areas X,Y,Z" or "How many subscribers are walking≥7 km/day?". The middleware parses the query and sends out sensing tasks to individual smartphones (using a specification called moments). It collects data, builds data models, and responds to queries. While doing so, it computes the spatio-temporal characteristics of the data demands of applications hosted in the platform and provides inputs to clients about these observed demand characteristics.

Vita stresses the relevance of providing crowdsensing as a service integrated with the usual software services and supports sensing task assignment based on user profiles (Xiping et al., 2013). To achieve the first goal, Vita relies on BPEL4PEOPLE, a Business Process Execution Language extension that enables the orchestration of human-driven sensing tasks within web services (Kloppmann et al., 2005). To achieve the second goal, Vita assigns a so-called “social vector” to tasks and users, which is a concise representation of user resources and knowledge, and exploits it to assign tasks to users whose profiles suggest that they may be willing to participate in that task and have enough resources to complete it successfully. The Vita cloud platform mainly consists of four components: management interface, storage service, deployment environment, and process runtime environment.

PEIR exploits mobile phones to evaluate whether users have been exposed to airborne pollution, enables data sharing to encourage community participation, and estimates the impact of individual user/community behaviors on the surrounding environment (Mun et al., 2009). The PEIR system will enable users to share their location traces with people they trust. But, in certain situations, individuals might not want to share all portions of their trace. A common privacy filter might be to hide a particular trip to a location (such as visit to the hospital, a certain store, or a particular restaurant). However, simply removing the trip is suspicious – the lack of data may focus attention on the space/time being protected. Thus, authors propose an approach that replaces a location trace segment to a particular significant destination with a trace that is most closely related to the original in terms of model output equivalency and is based on historical information relating to the user’s likely movements.

As we can see, most systems analyzed here focus on causing minimum interference with users’ lives by assigning tasks only to users who have a relatively tight matching context with the current task requests, as in Matador, USense and Vita. Accordingly, it is important to monitor users and to build a context capable of describing users’ behavior. It is important to keep this process simple as well as to maintain the full expressive power provided by the platform. Simple tasks combined with incentives, as seen in Medusa, are a relevant way of maintaining a good level of participation and willingness to contribute among users, a fundamental issue in any crowdsensing platform. Another important role is played by the mechanisms used for task definition: some systems capable of defining complex workflows, like Medusa and Vita, can be exploited to maintain simple tasks while defining more complex processes and combining data at a higher level.

Data Sensing

mCrowd is an iPhone app that enables users to post and work on sensor-related tasks, such as requesting photos of a specific location, asking to tag photos, and monitoring traffic. mCrowd currently supports four types of tasks: i) image tagging tasks, e.g. tagging objects in a query image; ii) image data collection tasks, e.g. obtaining images of a landmark; iii) textual queries from users, e.g. “what is the best restaurant in a city?”; and iv) GPS location-based queries, e.g. what is the nearest book store (Yan et al., 2009).

PEIR promotes intelligent decision-making through a review of observations, a comparison with similar situations and communities at a variety of scales, and a consideration of pattern variations over time. PEIR processing operates on GPS-enabled time-location traces (Mun et al., 2009).

By focusing on Ohmage, it supports both passive and active sensing actions (Ramanathan et al., 2012). One of the active actions makes it possible to create surveys that are either triggered at predefined times and locations throughout the day, or initiated in response to given conditions. Ohmage triggers can remind participants to respond to surveys; each trigger is attached to a single survey and is associated with time, location, and/or sensor readings. Each campaign can also collect actigraphy (a non-invasive method of monitoring human rest/activity cycles) data, using onboard GPS and accelerometers to elaborate high-level inferences about participants' activities, by returning a sampled activity recognition result once a minute along with location data.

In Matador, tasks can either be implicitly performed by smartphones after receiving user authorization (e.g. a GPS logging campaign), or explicitly performed by requiring user intervention (e.g. taking a photo of a given situation) (Carreras et al., 2013). Matador tries to optimize the location sampling time in order to minimize battery consumption by dynamically switching between network-based geo-location (power-efficient but inaccurate) and GPS (more power-hungry but also more accurate in outdoor environments). The intuitive idea behind adaptive energy-efficient user context sampling is to dynamically adapt the way the context is sampled and the time between two consecutive context samples. This is regulated by the proximity to one or more tasks, with the primary goal of using cellular network localization when approaching the closest task; in this case, the energy consumption should be quite limited. When the uncertainty on user location, due to the coarse accuracy of network localization, overlaps with the spatial validity of the closest task, Matador operates the switch to GPS localization; in this case, the location sampling time should vary over time on the basis of the approaching rate of the user to the closest task.

USense uses flexible policies for smartphone sensor duty cycling, which makes it possible to minimize the battery consumption of sensing activities (Agarwal et al., 2013). Four different sensing policies have been developed: Additive Back-off Multiplicative Advance, Multiplicative Back-off Exponential Advance, Additive Back-off Exponential Advance, Constant Sleep Time. All of them exploit a sleep time parameter, which is used to control the sampling frequency by specifying the time duration between two sensor readings; the dynamic variation of duty cycling is investigated to experimentally evaluate its impact on sensing cost, recall, and efficiency, while resource constraints are varied. The first three policies are adaptive in nature, i.e. they vary their sleep time based on the probability distribution of event occurrences; the fourth policy is non-adaptive and has a constant sleep time. USense clients (called USense instances) consider the input and autonomously decide on sensing policies, depending on other client-specific requirements and constraints (e.g. user preferences and available resources).

While some of the systems presented above gather data using smartphone sensors and can activate the process autonomously or after asking their associated users, others can start sensing at a specified location or time. This is the case of Matador, mCrowd, and PIER. In any case, even from this short list of projects, it is clear that GPS, used either alone or in combination with other sensors, is a primary sensing source exploited by these systems to connect sensed information to a specific location. Limiting energy consumption is another core feature that crowdsensing systems must include because it is crucial to enable long-term sensing campaigns without impacting too much on battery duration and without imposing specific requests on participants, such as the need to frequently recharge their smartphones.

Post-Processing

In Ohmage, responses are packaged up and returned over either cellular or Wi-Fi channels, to be monitored and displayed in soft real-time (Ramanathan et al., 2012). The Ohmage architecture includes an Android app to collect data and a back-end to administer data requests and to analyze/visualize collected data. Researchers can follow up with participants who are failing to upload consistently and can check for problems with hardware, software, motivation, or lack of technical expertise. Additionally, both researchers and participants can log-in to the system to visualize their uploaded data. Researchers can use tools to perform basic analysis, which can help to rapidly confirm the initial hypothesis and discover basic correlations. Participants can view their data to set and meet goals and to gain a sense of accountability for their behavior.

In Vita, the social vector is a tool which is applied to optimize the allocation of a task to a group of physical elements (e.g. people and cloud servers) (Xiping et al., 2013). It consists of various attributes about the information of a user and the computing resource available to her. Social attributes can be continuous, discrete, or boolean. Continuous social attributes include computing power (e.g. the number of floating-point operations that the device can perform per second), communication capacity (e.g. available bandwidth), and remaining battery time, which are obtained via a device implementation-independent API. Social attributes include the number of similar tasks executed, the number of remaining tasks, and the number of reused resources for a particular task, which are updated and recorded in each mobile device individually whenever a task is completed. Other social attributes, with boolean value, include whether a mobile user has related knowledge or prefers to accomplish a given task; these values are inserted by users during the deployment phase of a Vita crowdsensing application on mobile devices.

Apart from visualizing task results, the surveyed systems, such as Ohmage and Vita, use gathered information also to analyze crowd behavior and to build user profiles for better and more precise task assignment. Indeed, crowd behavior analysis is of paramount importance for effective task assignments, for maximizing user response, both in number and rapidity of responses, and for not bothering users who are not able or do not want to respond due to their current context.

Let us conclude this brief survey with some remarks. First of all, by focusing on socio-technical management aspects of crowdsensing platforms, tasks should be as simple as possible to encourage user participation; this could be facilitated by splitting complex crowdsensing campaigns into constituent sub-components and by independently assigning simple tasks that users can accept more freely. An approach similar to Medusa and Vita can simplify the achievement of this goal through task definition languages. Simple tasks are more easily accepted than complex ones and any system should avoid asking for big changes in user behavior by soliciting complex and unacceptable tasks they are likely to refuse. In particular, simple tasks are those ones that are not only easier to understand, but also require less time and physical effort to complete, by not disrupting user daily routine. Another important topic is how to minimize user workload and what kind of incentives are more effective in encouraging users to execute even more complex tasks.

Crowdsensed data should be refined by taking into account user trustworthiness (based on her history and reputation) and by enlarging the number of selected users for the same time (to polish data via non-minimal crowdsourcing). Users can provide fake data; it is possible to dynamically detect this, for instance, when a user completes several tasks that would require taking a photo in places that are several kilometers away in just a few minutes. In other situations, only human checking could validate the content, such as when a user, asked to take a picture of a monument, shoots a picture of her monitor that displays the requested monument. The inclusion of parameters that reflect these objectives into user behavior analysis, like the ones done by Ohmage and Vita, has demonstrated to relevantly improve the effectiveness of task campaigns.

A campaign that has the goal of reaching a minimal set of task-accepting users should fire an initial target number and, in the event of a limited number of responding users, should immediately attempt to involve new users to achieve the target number (even in successive task campaigns) rather than waiting for deferred acceptance. From our experience, users can be classified into two main classes based on their behavior: users immediately deciding for acceptance (in either positive or negative way), and users who prefer deferring the decision until task expiration instead of refusing it explicitly. According to our analysis of task results, users are more likely to ignore a task rather than reject it.

THE PARTICIPACT CROWDSENSING LIVING LAB FOR SMART CITIES

As anticipated in the previous section, crowdsensing issues are not only very complicated but also deeply interconnected, yet there are no clean and easy-to-follow strategies in this area. We felt the need for a new crowdsensing infrastructure, ParticipAct, which started within the city of Bologna and connected with the students of the University of Bologna. ParticipAct intends to make it possible to verify any desired crowdsensing strategy in the field and identify suitable crowdsensing policies. The ParticipAct experiment engages 150 smartphone-provided students for one year of active participation: enrolled students can passively collect data on their smartphones, but can also carry out some requested activities in their normal local areas.

ParticipAct is the complete supporting infrastructure that allows for local actions and the client collection of data, that transfers sensed data to the back-end support, and that takes over not only data harvesting but also post-processing, mining, and maintenance. The role of controlling all policies and driving the whole scenario is given to a supervisor that is in charge of strategies to orientate the participating behavior and also of analyzing available information. The ParticipAct supervisor and, in a more general sense, smart city controllers can enforce different actions and policies according to changing requirements.

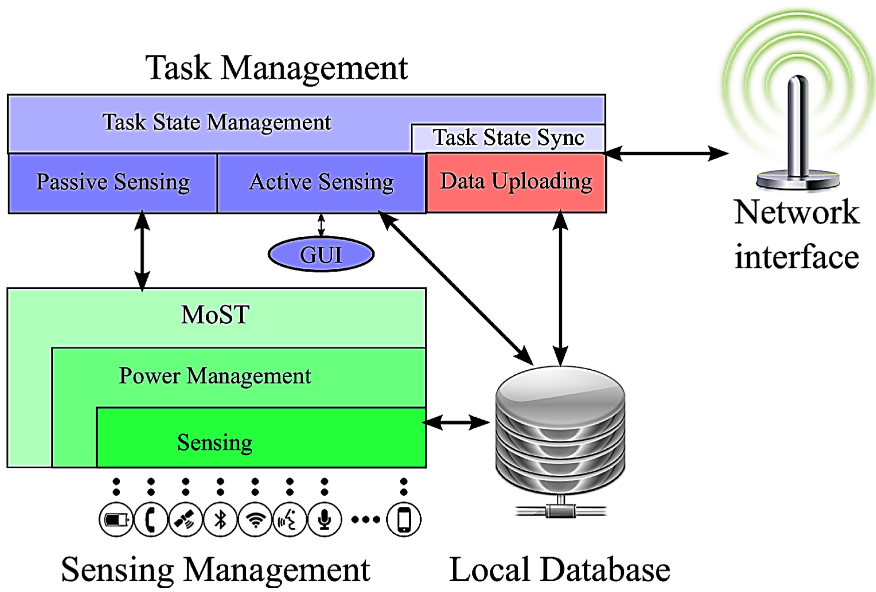
The ParticipAct infrastructure can be considered from multifold perspectives:

- A long lasting and large *Living Lab for crowdsensing* to test and devise new strategies (it is a year-long experiment). After the boost phase, for the whole of 2014 new trends, actions, and policies can be proposed, tried, and tested;
- A large collection of *stream data* coming from different sources connected with a smart cities experiment with a significantly large harvesting of data, guaranteed by students living in Bologna and nearby areas;
- A large *experiment on its students' habits* driven by the University of Bologna, to better understand their profiles and their needs, so as to provide better and more tailored services.

With these goals in mind, and following the main design guidelines deriving from our taxonomy of existing crowdsensing systems, we realized the ParticipAct infrastructure. The nature of ParticipAct requires a client-server architecture: a client running on a user device as a smartphone app currently available for Android takes care of receiving tasks and running them and sending all the results to a server that can store, analyze and use them.

The ParticipAct client (see Figure 6) is the component that takes care of receiving tasks, asking users whether they want to run them, managing data collection, and uploading results. Functionally, the ParticipAct client comprises two main components: the *task management* component and the *sensing management* component (Figure 3).

Figure 6. The architecture of the ParticipAct client



These components orchestrate the full lifecycle of tasks on user devices, and are responsible for both interacting with users and accessing smartphone sensors.

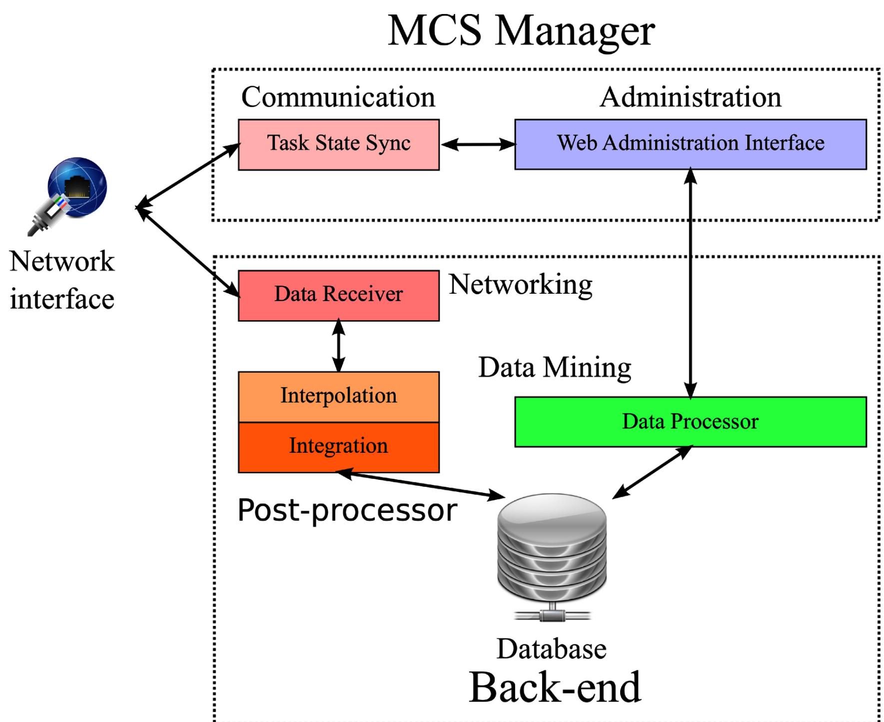
The *task management* component takes care of overseeing the whole task lifecycle on smartphones. It has five main responsibilities: i) receiving tasks from the server and keeping their state synchronized; ii) providing users with an interface to control task execution; iii) implementing the Graphical User Interface (GUI) for active sensing actions that require user interaction (see Figure 4); iv) driving sensing actions; and v) uploading sensed data, by locally storing them in the local database, and then sending them to backend components. Due to space constraints, we will not detail here all of the internal functions of our client, for which we refer interested users to Cardone et al., (2013b).

The sensing component, meanwhile, is built atop MoST, an open-source Android sensing library that provides a uniform access layer to all physical and logical sensors (Cardone et al., 2013a). MoST eases the burden on app developers that want to use sensor data by providing data processing and power management, while taking into account concurrency issues due to access to shared resources, thus making sensing un-intrusive and minimizing the impact on the user experience. While MoST is a general-purpose library, in ParticipAct it effectively implements all passive sensing actions.

The server side of ParticipAct provides for the management, storage and analysis of crowdsensed data. At the highest level it comprises two main parts, as shown in Figure 8: the *Back-end* and the crowdsensing *Manager*. The *Back-end* takes care of receiving, storing, and processing sensed data, while the *Manager* provides the administrative interface to design, assign, and deploy sensing tasks.

Apart from the communication components, the *Back-end* includes and realizes interpolation and integration post-processing functions as well as data processing functions to derive user profiles. As regards the Manager, this is the administrator-facing part of ParticipAct that exploits the data processing and data mining features exported by the Back-end to provide administration features. The *Web Administration Interface* (Figure 9) is the point of interaction between managers of crowd-

Figure 8. Server-side architecture of ParticipAct



sensing campaigns and the ParticipAct system. ParticipAct adopts a template-based definition model that allows for the full administration of the whole crowdsensing, including the management of user profiles, the design and assignment of tasks, and data review.

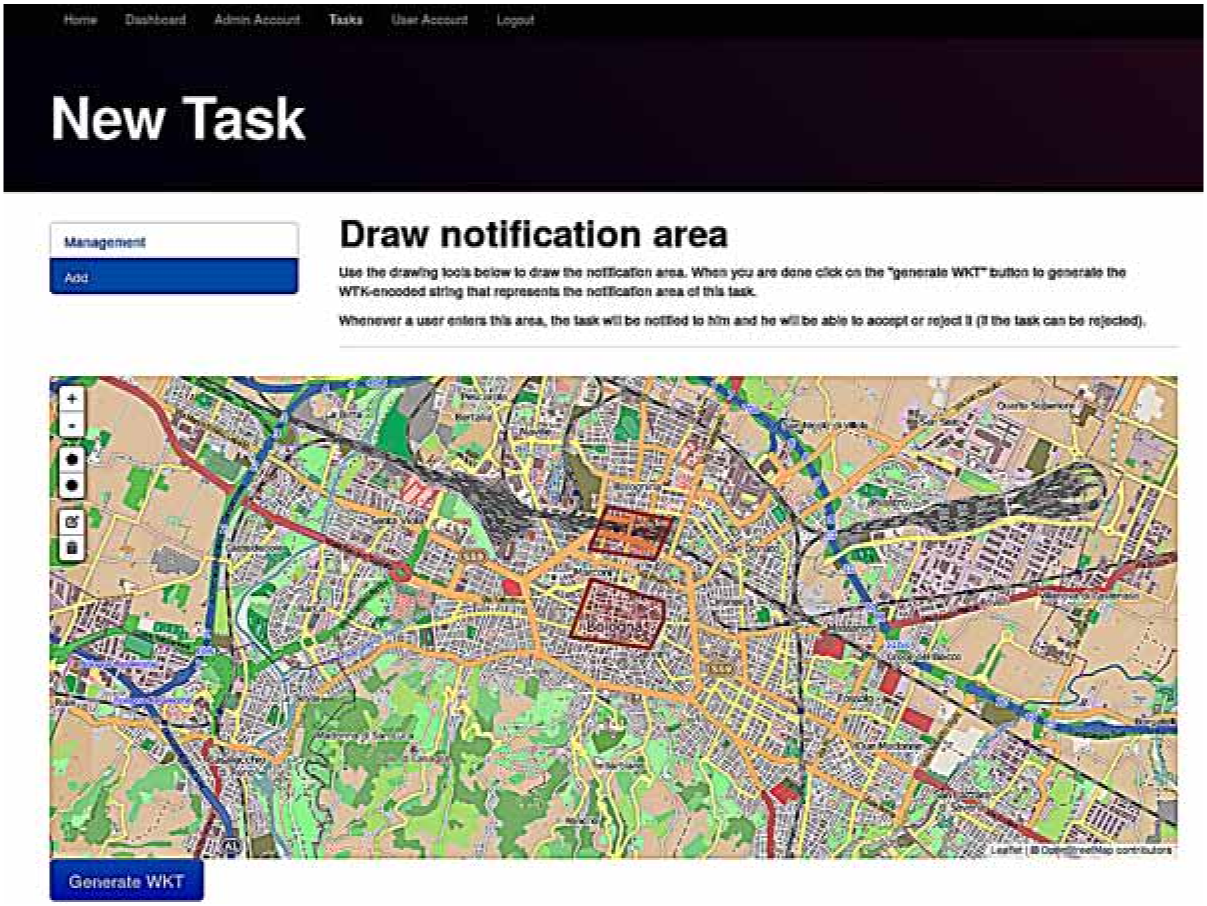
The Web Administration Interface does not require any specific technical knowledge and provides easy step-by-step wizards for each complex operation (e.g. creating a new task), thus minimizing the access barrier to ParticipAct (Figure 10). A core function of the Web Administration Interface is its ability to tap into results provided by the Data Processor to automatically assign tasks to users that are more likely to successfully execute them.

In the following, we report on two case study scenarios and related experimental results: the first one focuses on an advanced mobility mode recognition analysis (exploiting both client-side sensing and server-side post-processing), while the second focuses on task management.

Mobility Mode Analysis

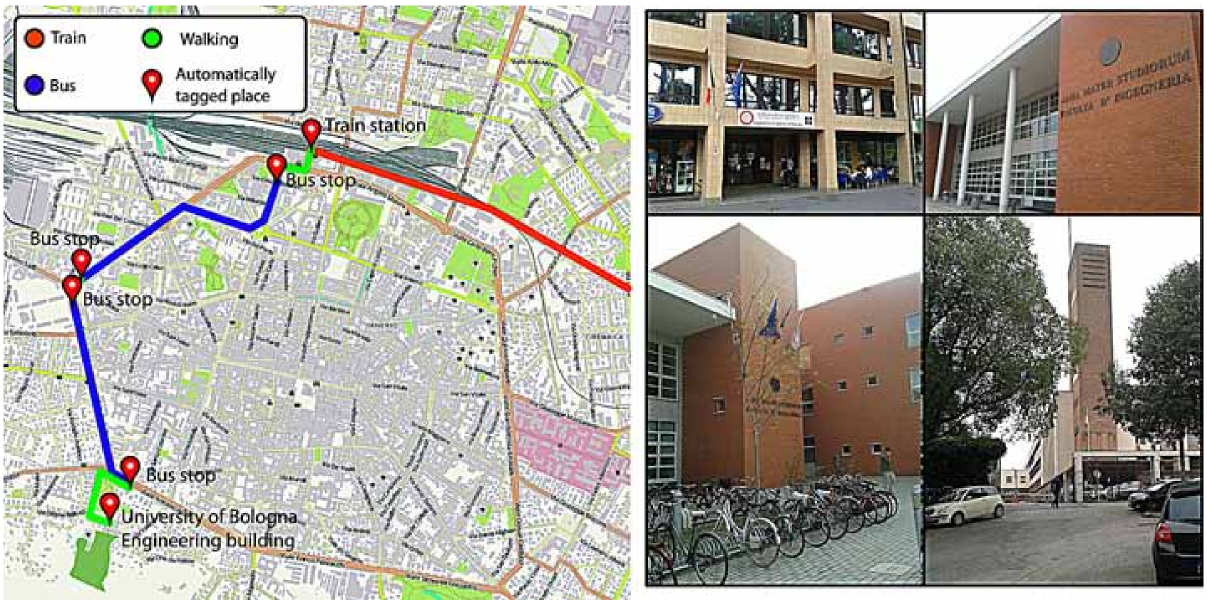
To challenge the capabilities of ParticipAct MoST, we developed a Mobility Mode Analysis (MMA) module for profiling at the Data Processor. MMA exploits geolocalization and physical activity recognition to infer from raw data the preferred routes of users and how they travel along these routes. MMA integrates punctual and disconnected raw data to provide a more meaningful view of users by making it possible to easily and quickly answer questions such as what are the preferred areas for walking/driving/biking, what is the preferred mobility mode by time and/or place, and so on.

Figure 9. Screen capture of the ParticipAct Web Administration Interface, e.g. the interactive page for the definition of the geonotification area of a task



With a closer view on technical details, MMA outputs places where users rest and usually stop (e.g. home, workplace, restaurants) tagging them with human readable descriptions, and it also connects them trying to infer the exact route and how the user moved, i.e. by walking, bike, and vehicle (train, bus, and car). Rest places, where the user rests for a while, are computed by aggregating geolocalized points that are very close both geographically and temporally, i.e. if no movements are registered for more than a threshold time. The MMA module then uses Foursquare API to run a search of venues in that area and uses the most popular location to tag the rest place; in our tests, this simple technique worked reliably for popular places attended by students, such as university buildings and nearby cafeterias. Then, MMA infers how users move from one place to another by employing physical activity recognition data (namely, standing still, walking, running, biking, being in a vehicle), the results of which are further refined by exploiting all available information that could help to link GPS coordinates with meaningful physical locations useful for distinguishing the mobility mode, such as train stations and bus stops obtained from Google Directions and Places API; shape files from OpenStreetMap for roads and train railways; and shape files from the local Bologna bus company for bus routes. If a user activity is classified as "travelling by

Figure 10. (a) Mobility mode inferred by the MMA module of a student arriving in Bologna by train and travelling by bus to reach our university building; the "walking" recognition at the middle of the bus route between the train station and the university is one missed "bus" recognition. (b) Some photos of the university building taken by ParticipAct users as part of a photojournalism task.

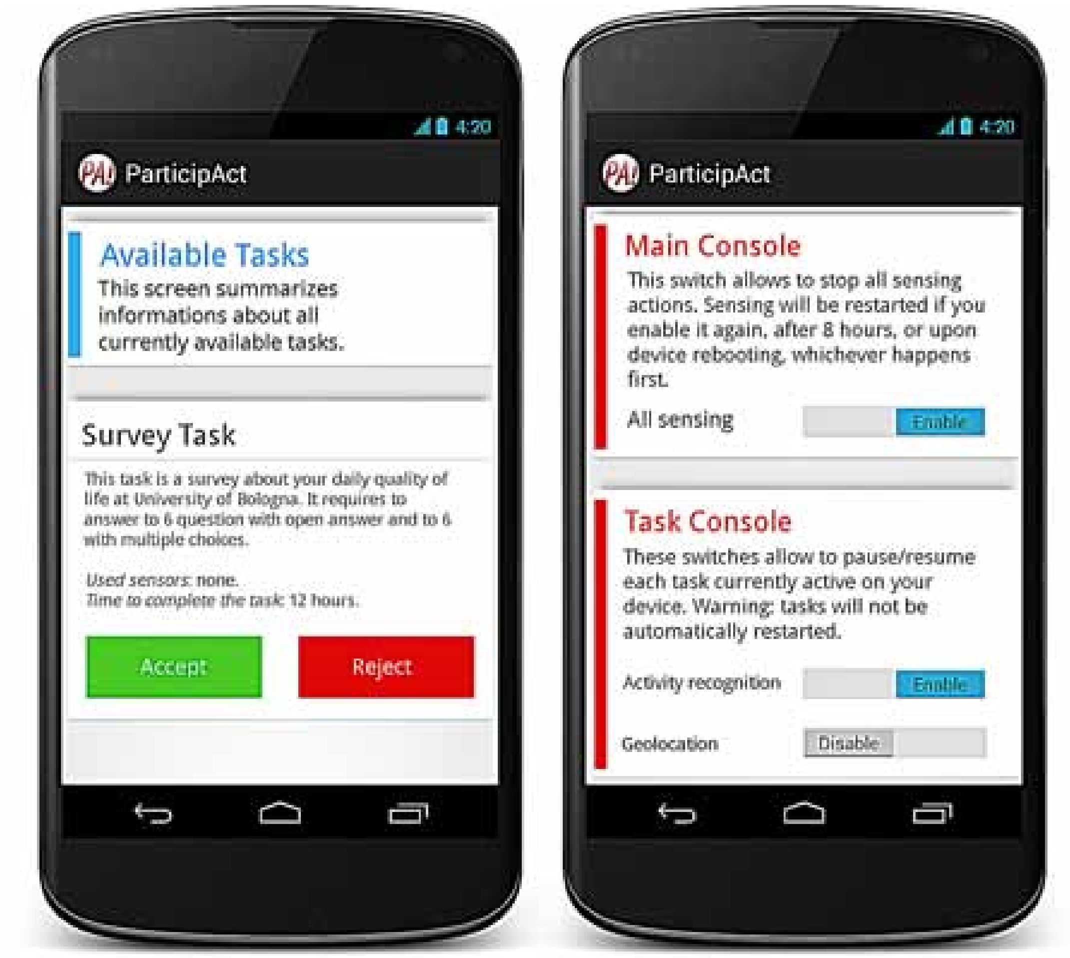


vehicle", and she has stopped by a train station before starting to move, and then very closely followed the railway, then her mobility is narrowed down to "travelling by train". Figure 7-(a) shows an example of the mobility data inferred by this module, and seminal performance results range from a very good 98.5% for "walking" to 62% for "by bus" with plenty of room for improving the specific vehicle mobility mode recognition, that we want to further refine also using historical data not used by current MMA implementation.

Collaborative Journalism

ParticipAct enables the active collaboration of users who collect data that would not be easily or inexpensively available otherwise. Hence, to show the potential of our support, we developed a simple "collaborative journalism" use case, in the sense of the crowdsensing activity of taking pictures of a given place at a given time. We asked users to document events and places with photos, and we used ParticipAct to handle the performance and the success of these tasks in real time. During the first three months of our field trial, five times we asked all 150 users to take a picture of well-known areas within the city limits that are easily reached and often crowded: users successfully submitted a valid picture 60% of the time. During the same period, we activated user analysis and ran the same five tasks again: this time we assigned the task only to people that, based on their profile, were recently in the areas of interest passed by most frequently. In these cases, on average Data Processor selected 12 users only, and the ratio of users that successfully completed these tasks by uploading a valid picture was, on average, 44% of the selected people, showing that by carefully selecting a very small group of users we managed to complete the task anyway. Figure 7-(b) shows

Figure 7. The ParticipAct client running on smartphones, e.g. the GUI to accept/reject a task and the console that makes it possible to pause the sensing features



some of the photos taken by ParticipAct users when asked to take a picture of a university building.

Although this seminal use case is small, it shows that profiling users is very beneficial for crowdsensing: with simple processing, we were able to reduce the number of users involved in a sensing task by more than 90%, thus reducing the workload on participants and without decreasing the number of successful tasks too much. A side effect of better user targeting is saving network resources on both the client and server side: in fact, assigning the photo tasks to all users resulted in an average of 180 MB of transferred data per task, while in the second case it sharply decreased to an average of 11 MB per task. Thus, user profiling allows for a better exploitation of both human and technical resources.

CONCLUSION

Crowdsensing enables new application scenarios without the need for costly infrastructure investments, such as the smartphone-based gathering of several different types of sensing data to enable smart management actions in contemporary Smart Cities. Indeed, currently available smartphones and sensing libraries are powerful sensing platforms that allow us to obtain sufficiently precise and accurate activity detection and several different high-level inferences.

This chapter described current state-of-the-art and research trends in crowdsensing platforms for Smart Cities, which is currently a very lively and active area. Of the many ongoing projects worldwide, we have presented ParticipAct, our original crowdsensing project at the University of Bologna, which involves 150 students in a large-scale urban crowdsensing experiment. We believe that ParticipAct could pave the way to a new generation of real-world large-scale crowdsensing testbeds, capable of truly verifying any step in the crowdsensing process, from task scheduling to incentive management and mobile sensing, with the ultimate goal of becoming an effective monitoring solution for our future Smarter Cities.

REFERENCES

Agarwal, V., Banerjee, N., Chakraborty, D., & Mittal, S. (2013). USense - A Smartphone Middleware for Community Sensing. In *Proceedings of 14th IEEE International Conference on Mobile Data Management* (pp. 56-65). doi:10.1109/MDM.2013.16

Bernstein, M. S., Karger, D. R., Miller, R. C., & Brandt, J. (2012). *Analytic Methods for Optimizing Realtime Crowdsourcing*. Collective Intelligence.

Cardone, G., Cirri, A., Corradi, A., Foschini, L., & Maio, D. (2013a). MSF: An Efficient Mobile Phone Sensing Framework. *International Journal of Distributed Sensor Networks*, 2013.

Cardone, G., Foschini, L., Bellavista, P., Corradi, A., Borcea, C., Talasila, M., & Curtmola, R. (2013b). Fostering participaction in smart cities: A geo-social crowdsensing platform. *IEEE Communications Magazine*, *51*(6), 112–119. doi:10.1109/MCOM.2013.6525603

Carreras, I., Miorandi, D., Tamilin, A., Ssebaggala, E. R., & Conci, N. (2013). Matador: Mobile task detector for context-aware crowd-sensing campaigns. In *Proceedings of IEEE International Conference on Pervasive Computing and Communications Workshops* (pp. 212-217). doi:10.1109/PerComW.2013.6529484

Ester, M., Kriegel, H.-P., Sander, J., & Xu, X. (1996). A density-based algorithm for discovering clusters in large spatial databases with noise. In *Proceedings of 2nd International Conference on Knowledge Discovery and Data Mining* (pp. 226-231).

Fogg, B. J. (1998). Persuasive computers: perspectives and research directions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 225-232).

Fogg, B. J. (2002). *Persuasive technology: using computers to change what we think and do*. Burlington, MA: Morgan Kaufmann Publishers.

Fogg, B. J. (2009). A behavior model for persuasive design. In *Proceedings of 4th International Conference on Persuasive Technology* (pp. 1-7).

Ipeirotis, P. G. (2010). Analyzing the Amazon Mechanical Turk marketplace. *XRDS: Crossroads - The ACM Magazine for Students, 17*(2), 16-21.

Kloppmann, M., Koenig, D., Leymann, F., Pfau, G., Rickayzen, A., von Riegen, C., . . . Trickovic, I. (2005). Ws-bpel extension for people–bpel4people. *Joint white paper, IBM and SAP*.

Lane, N. D., Miluzzo, E., Lu, H., Peebles, D., Choudhury, T., & Campbell, A. T. (2010). A survey of mobile phone sensing. *IEEE Communications Magazine*, *48*(9), 140–150. doi:10.1109/MCOM.2010.5560598

Mun, M., Reddy, S., Shilton, K., Yau, N., Burke, J., Estrin, D., & Boda, P. et al. (2009). PEIR, the personal environmental impact report, as a platform for participatory sensing systems research. In *Proceedings of 7th International Conference on Mobile Systems, Applications, and Services* (pp. 55-68). doi:10.1145/1555816.1555823

Ra, M.-R., Liu, B., La Porta, T., & Govindan, R. (2012). Medusa: A Programming Framework for Crowd-Sensing Applications. In *Proceedings of 10th International Conference on Mobile Systems, Applications, and Services* (pp. 337-350). doi:10.1145/2307636.2307668

Ramanathan, N., Alquaddoomi, F., Falaki, H., George, D., Hsieh, C., Jenkins, J., & Estrin, D. et al. (2012). ohmage: An open mobile system for activity and experience sampling. In *Proceedings of 6th International Conference on Pervasive Computing Technologies for Healthcare* (pp. 203-204). doi:10.4108/icst.pervasivehealth.2012.248705

Xiping, H., Chu, T. H. S., Chan, H. C. B., & Leung, V. C. M. (2013). Vita: A Crowdsensing-Oriented Mobile Cyber-Physical System. *IEEE Transactions on Emerging Topics in Computing*, *1*(1), 148–165. doi:10.1109/TETC.2013.2273359

Yan, T., Marzilli, M., Holmes, R., Ganesan, D., & Corner, M. (2009). mCrowd: a platform for mobile crowdsourcing. In *Proceedings of 7th ACM Conference on Embedded Networked Sensor Systems* (pp. 347-348).

KEY TERMS AND DEFINITIONS

Android: Mobile platform to support mobile app development, with multiprocessing capabilities.

Crowdsensing: Measurement and collection of data through different kinds of sensing devices (e.g., smartphones) by a large mass of users, with the goal of sharing collected data with Smart City citizens through a common ICT platform for the sake of the community wellbeing.

Crowdsourcing Task Management: Managing and soliciting participatory contributions from groups of people. The goal is to achieved crowdsensing data via tasks proposed to users by a crowdsourcing management platform.

Data Processing: Collection and elaboration of sensing data with the aim to derivate/infer new knowledge from original raw data.

Mobile Middleware: Middleware developed to effectively and efficiently support the runtime provisioning of mobile services, typically exploiting wireless communication technologies.

ParticipAct Living Lab: The University of Bologna crowdsensing platform that combines efficient task management and data processing capabilities.

User Participation: Contribution by users interested in participating to data sensing/collection, who typically reply positively to task invitations in the context of a wider data collection campaign.

Chapter 16
Visualising Data for Smart Cities

Michael Batty
University College London, UK

Stephan Hugel
University College London, UK

Andrew Hudson-Smith
University College London, UK

Flora Roumpani
University College London, UK

ABSTRACT

This chapter introduces a range of analytics being used to understand the smart city, which depends on data that can primarily be understood using new kinds of scientific visualisation. We focus on short term routine functions that take place in cities which are being rapidly automated through various kinds of sensors, embedded into the physical fabric of the city itself or being accessed from mobile devices. We first outline a concept of the smart city, arguing that there is a major distinction between the ways in which technologies are being used to look at the short and long terms structure of cities, and we then focus on the shorter term, first examining the immediate visualisation of data through dashboards, then examining data infrastructures such as map portals, and finally introducing new ways of visualising social media which enable us to elicit the power of the crowd in providing and supplying data. We conclude with a brief focus on how new urban analytics is emerging to make sense of these developments.

DEFINING SMART CITIES

The term 'smart cities' has emerged very quickly over the last five years[1]. First, this has been a consequence of the rapid spread of computation into public and open environments, into what Hardin (1968) and others have called the 'commons', spaces that are used and exploited collectively. Second, it has been spurred on by the miniaturisation of computable devices to the point where tiny sensors can be embedded into objects of many different sizes, from buildings to our own bodies, thus generating digital information concerning the status, the condition, location and so on, of the objects in question. This feature of the smart cities movement is often referred to as the Internet of Things (Sterling, 2005). A third force is the emergence of digital data in space and time, that is, in terms of how an object's status varies in real time and across different spatial locations, and this data is invariably orders of magnitude bigger than anything we have dealt with in the human domain so far. This 'big data' is providing a very different perspective on the way we might understand our cities while also revealing how new information technologies are changing the very

DOI: 10.4018/978-1-4666-8282-5.ch016

behaviour patterns that make up the contemporary city (Kitchin, 2014a). Google Trends reveals that this interest concerning smart cities and big data is still rising exponentially, as an analysis of the relevant search terms demonstrates (Batty, 2013).

A smart city also implies some degree of intelligence, some set of computable and automated functions that act intelligently with respect to the way the city actually functions through its populations. In this sense, smart cities have been embraced as the new frontier by the world's largest IT companies whose products, which have evolved from hardware to software and data, are further evolving into systems that might be embodied in the public domain where the obvious applications involve making collective actions more efficient. To an extent, the smart city movement barely touches the traditional questions of equity and distribution which have dominated city planning for over a century, although some lip service is currently being paid to the fact that new information technologies might make cities more prosperous in terms of income and wealth and, as a consequence, perhaps more evenly distributed.

'Smart cities' is a label that is now being used generically to cover a very wide range of applications of computers, sensors, and related computation and interaction that has any link whatsoever to the city. It is such a broad domain that it is essential, in any discussion, to bound the area and define its scope. The focus here is on the immediacy of new data and functions that define the smart city with an emphasis on their use and understanding using visualisation, but to set this in context it is worth providing some overall structure for different approaches to the idea of the smart city. For more than a century, the general concern for cities as regards urban planning has been on how cities can be improved over relatively long time spans. In this sense, the knowledge that is brought to bear on cities can be somewhat abstract, conceived in terms of how locations and interactions through transport can be orientated to thinking of future forms and functions for cities that might optimise some quality of life. Every planning instrument, from new towns to green belts, has been predicated with these goals in mind, where the emphasis is not particularly on the routine but on the strategic. Insofar as planning has dealt with routine functions, this has tended to be subsumed under organisational and management structures that say little or nothing about how cities might become more equitable. The focus on short-term management goals is in fact more geared to improved efficiency. To date, many of these routines have not been informed by digital technologies, in contrast with longer-term plan-making which has been so informed, albeit crudely, but not without considerable debate and controversy.

There is thus a major distinction between digital technologies being used for the short-term routine management of cities and those for longer-term strategic planning, and this difference is reflected in much of the data, information and knowledge that pertains to the functions that smart city technologies are able to inform. Furthermore, there is a distinction between public and private use. In the past, data on individuals, insofar as they provided information about their own functioning in cities, was produced for aggregates of population using traditional surveys such as censuses. Individually specified data tended to be in terms of the role of citizens in participating in the decision process. This has changed radically in that individuals are now able to record their own behaviours passively or actively using multiple personalised devices which are extensively linked through digital networks. In turn, these provide massive amounts of data that can be mined to facilitate a better understanding of how cities function, at present mainly in the short term, but in time as this kind of data accumulates, in the longer-term too.

In fact, the term smart cities pertains much more to the routine management of cities in the very short term: with respect to how cities function in the next 5 minutes, the next 5 hours, the next 5 days rather than the next 5 years or 50 years.

This is largely because smart city technologies which lie at the leading edge of current computable devices are strongly orientated to sensors with big data generated, if not used, in real time. Instant messaging and related website presence also implies various kinds of social network, while telephone traffic is fast merging with other media, and consumer purchase data of all kinds is also being generated on short time cycles. Combine all this with financial information in real time and the shortening of our attention spans with respect to the emergence of the smart city is clearly evident. Of course, there are some attempts to look at longer-term data, which can be assembled from individual responses such as house and land prices, income data, retail prices, employment, migration and so on, but so far most of the focus in smart cities has not been on these traditional concerns. Smart cities tend to be all about how big data can be used to examine mobility, social networks and individual preferences data by way of crowd-sourcing, and, to an extent, online citizen participation. It may not always be the case but currently this is the dominant preoccupation in this domain and quite unashamedly we will exploit this here in our focus on how new visual technologies are able to capture this new concern.

We will begin by sketching the rudiments of a conceptual approach to smart cities, concentrating on short-term issues which involve how computation is changing the way we deal with routine travel and communications using embedded sensor technologies to mobile devices operated through a range of media, from machines to humans. The focus of the smart city in this domain is on control and management from the data that is generated in real time and this 'big data' provides a new level of complexity with respect to the way we make sense of mobility and interaction in terms of anything we have been able to do hitherto. Visualisation is the obvious medium for its simplification and abstraction and this is leading to many kinds of infographic that are being used for the control as well as the automation of these kinds of system, particularly transit. New varieties of analytics are emerging to make sense of such data and we will focus on how new ways of computing are being used to make such systems more efficient through real-time control.

In fact, so far many of these technologies have not been realised. The larger computer companies, which see these markets as their domain, have only a limited number of solutions that have been tried and the history of these applications to date has not been a happy one. In short, real-time control, interoperability of systems, and the use of big data to provide a seamless understanding of how such systems can be made more efficient is more myth than reality and the promise of these systems is yet to be realised on anything other than the very small scale. We will sketch possibilities in this chapter making the point that the simplest and most straightforward of smart city technologies are those that currently exist, such as dashboards and control centres. To conclude, we will examine the prospects for developments in this domain and point the way to how technologies for short-term control might lead to longer-term strategic management and policy-making once such systems become established and more long-lived. Reviews of smart city applications so far are highly diffuse but readers who wish to review the wider context are referred to the paper by Batty et al. (2012) where the range of tools and methods used to understand and implement smart city ideas are reviewed.

A CONCEPTUAL MODEL OF THE SMART CITY: ROUTINE FUNCTIONS, NETWORKS, AND NEW MEDIA

The first signs of computational technologies (that we define as digital rather than analogue) becoming embedded into cities came in the late 1980s with the emergence of local and wide area networks (LANS and WANs) and the development of digital mobile phones. This represented one aspect of the convergence of computers with telecommunications which in itself was unexpected when digital computers were first invented. Miniaturisation also played its part and, combined with the development of widespread interactive computing during those years, provided a new sense in which those living and working in cities could communicate. In fact, cities are all about communication and thus flows and networks are central to any model of the smart city. Equivalent new technologies have of course existed since the telegraph and telephone were invented in the 19th century, but it was only when these technologies became interactive and, indeed, all-pervasive that the notion of the city itself becoming computable heralded in the age of the smart city. In the 1980s, the idea that economic development could be spurred by the location of fibre optics was widely explored as a basis for improving the prosperity of cities, and early municipal information systems were proposed as technologies to deliver public services. But it was not until the mid-1990s with the widespread development of mobile devices and wireless networks coming into their own that the idea of the computable city became a reality (Batty, 1997). The web, of course, was the progenitor of the smart city but the idea too that these technologies were replacing or at least complementing traditional physical and analogue technologies also suggested that smart cities, the key to a post-industrial world, might be much more complex than cities of the industrial and pre-industrial past.

What is very clear from the embedding of computational devices into the very fabric of the city across many scales is that cities are not managed or controlled from the top down. The emergence of social media is enough to convince one that cities do not function from top-down control no matter how many proposals are implemented that assume this to be the case. It has long been agreed amongst urbanists that cities grow and evolve from the bottom up (Jacobs, 1961), through the action of millions of individual decisions with more aggregate decisions still being generated by individuals no matter how much these may look like top-down control. Individual actions of course range from the simplest decisions about where to move to on a daily basis to where to locate for longer term advantage, but all such decisions are grounded in real time. These are being dramatically informed and transformed by new information technologies and this has heralded a shift in our thinking about cities to the short-term, to actions and decisions that happen on a diurnal cycle or shorter time intervals, in contrast to decision making that in the past had only been possible to observe over much longer time periods.

There is an irony in all of this. We do not have a good conceptual model of how a city functions in the very short term, where all the current activity associated with the smart city is taking place, whereas we do have models, albeit not very good ones, of how cities evolve in the longer term. Essentially, our vision of how cities evolve in terms of the structuring of their land use in organised spatial clusters and how their densities react to changes in demand and supply for land and capital, are based on models that examine how decisions that take time are made. Insofar as we have models that deal with short- and long-term decision-making, we simply assume a disconnection between how we act in the short term with long-term decisions, although it is increasingly clear that there are important feedbacks taking place that we should account for between the short- and long-term.

There are almost as many theories of the city as there are individuals attempting to make sense of these phenomena, with the field being clearly multi-paradigmatic or pluralistic. No good theories of the smart city in the short- or long-term exist, but to make progress here we can define some elements that pertain to the dynamics and structure of cities in the short term involving activities and interactions that take place in cycles that cluster around mobility during the working day and the delivery of services that take place over time periods on monthly cycles. These merge, of course, into longer-term change but our focus here is on how these shorter-term cycles are being 'informated' by new technologies. We have already noted that complexity science, with its focus on understanding systems from the bottom up, is key to our approach and this is manifest by the rapid growth of ideas about how networks are formed and how new technologies are reinforcing and generating networks of flows. These range across social and economic functions that involve interactions between people, but they are increasingly measured in non–physical terms – not in terms of people, energy or commodity flows but in terms of information flows, the flow of ideas, and the flow of money, which is a virtual commodity in itself. These are extremely hard to observe and our accounting systems are quite inadequate to provide any degree of comprehension which might underpin the way individuals and groups are making decisions based on electronically transmitted information.

This is best seen in the rise of social media. Much emphasis in the smart city is on making sense of how cities function from the vast volumes of interactions that individuals now organise through web services. These range across everything from Facebook to Google searches, through tagging mobile phone calls (from Call Detail Records – CDRs) to locations that can be associated with particular attributes such as work and play, but also through the variety of short text messaging and related services, of which Twitter is the example par excellence. Much of this data is highly ambiguous and can be positively misleading and, although interesting in its own right as we reveal below, there are considerable barriers to its use in understanding its meaning for the functioning of the contemporary city.

The single biggest problem in developing strategies for developing new technologies that make cities more efficient is that their effect involves a degree of invisibility that is different from traditional urban functions that depend on traditional technologies. In terms of how labour and capital are deployed in the industrial city to generate work, physical movements of activities – people and goods – predominate and these are comparatively easy to observe. Information flows, which have dramatically expanded through the internet, now provide massive input into production and consumption and their impact on physical flows and interactions is extremely hard to disentangle. This merger of the real and the physical makes the smart city considerably more complex to engage and understand than any city in any previous era. This transfer of atoms to bits, as Negroponte (1995) so presciently called it, is the dominant signature of the contemporary city and one of its consequences is that interactions within the population have multiplied massively as new and more immediate modes of communication have proliferated. This is seen clearly in the proliferation of social media, which is being used for a very wide range of functions which are increasingly almost too cryptic and complex to disentangle.

Automation in physical interactions is also a key feature of the smart city. Technology in cars enables better driving and communication with systems that enable better navigation utilising GPS, crowd-sourcing and other data pertaining to the transportation systems, such as that provided by services such as Waze (https://www.waze.com/). There are many developments which merge the physical and virtual in terms of the way information about the state of the physical system influences the way users engage with it and this is complicating analysis in ways that are unprecedented and for which we have a paucity of new approaches. Many new forms of information system are being introduced into cities in an attempt to control public access to services and one of the goals of many of the large IT companies, such as IBM and Cisco, in their smart cities projects is to ensure good integration between diverse systems, thus adding value to the entire enterprise. But a lot of this is mere hype. It is difficult, if not impossible, to correctly merge data sets that do not have common keys, and although there are ways of approximating such linkages, the state-of-the-art in this remains primitive. In the geospatial domain, address points, zip codes or their equivalent, is the usual way but even in relatively unambiguous contexts, where such a common key exists between two or more data sets, there are often problems of quality and completeness. In short, the notion of a seamless set of information systems where different activities in the city can be controlled from some common portal or frame remains a dream of the smart city optimists and is likely to remain so. An extreme version of such integrated technologies is the notion of an operating system for the smart city such as that proposed by PlanIT (http://living-planit.com/UOS_overview.htm). But such plans must be treated in somewhat allegorical terms as their realisation is simply impossible, sometimes betraying the naïve idealisation about how cities work that tends to characterise many of those thinking, writing and trying to implement technologies that compose the smart city. A generous interpretation of much of this hyperbole would be to assume that it represents directions for debate rather than serious practical proposals for action.

There have been attempts at bringing new technologies to the city to deal with routine events before. In the 1960s, technologies developed for dealing with political strategies in the Cold War – game theory, operations research, and information systems – were applied quite widely to the problems of the emergency services particularly in large US cities where the focus on deprivation and local resourcing had become urgent due to de-industrialisation, poor infrastructure and ethnic conflict. Various models of resource allocation for quite well-defined problems had been researched and applied at places like the RAND Corporation in the 1950s and 1960s and it appeared that the judicious application of these tools to urban emergency services might provide efficient methods for resolving key urban problems. It is important to note that these represented the application of computer models to problems where the data was adequate and which were controlled by agencies entirely within the purview of local municipalities, such as police and fire services. In fact, the experience of these first applications of smart city technologies was disastrous largely due to the inability of all the stakeholders involved to appreciate the many different perceptions of the problem, the politics involved in terms of traditional and new ways of working, and the generally volatile context of these problems, which were part of the wider decay in US cities due to factors well beyond the control of the municipalities themselves. Flood (2011), amongst others, paints a picture of classic wicked problems that get worse as seemingly more sophisticated methods were put to work on solving and alleviating them. Given this history, the portents for the current generation of smart city technologies are not good, particularly as this time around the key actors in the process – the large software and networking technology companies – are in the game so that they can make money. 50 years ago this profit motif was not to the fore in quite the same way (Greenfield, 2013).

It is quite clear that we do not really have a comprehensive theory which provides us with an integrated view of how new digital technologies are affecting the form and function of the contemporary city, apart from the straws in the wind noted here. There is little sense of joined-upness in the way new network technologies are being developed and how these might integrate different human behaviours which, in turn, will change the way the city is structured. To an extent, this is because many of these technologies are potentially disruptive, providing new modes of working that do not replace but simply add to conventional ways of doing things. In a sense, those who have attempted to look at these in a wider context have been forced back to first principles in terms of thinking what cities are for, how they work and how they act as social and economic drivers to increase prosperity and quality of life. Harrison et al. (2010) have sketched a context for the approach to smart cities through infrastructure, and extended this to embrace wider issues that tend to see these developments in context (Harrison & Donnelly, 2011). But our sense of the terrain is still extremely patchy and this discussion seems to miss so much of what cities are all about while at the same time appearing to pervade every aspect of the city as any universal technology will surely do.

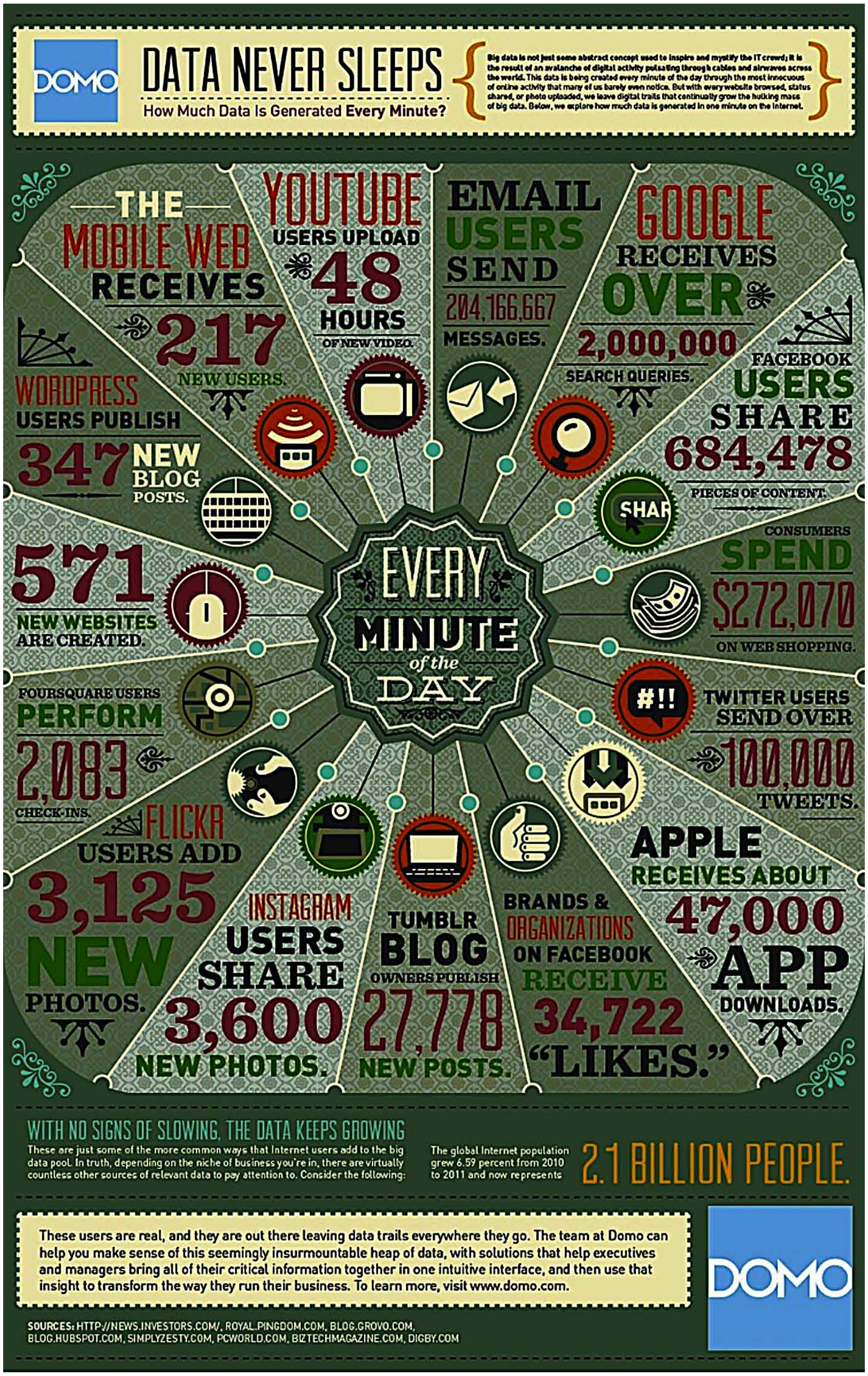
IMMEDIATE VISUALISATIONS

Using our narrower perspective on the smart city, which focuses on the use of computation and sensors to automate routine systems which operate at high frequencies, real-time data streams tend to dominate the development of integrated systems for control and management. This is the focus of IT companies such as IBM through their Smart Planet initiative and it is therefore not surprising that those responsible for the wider coordination of such technologies, largely municipalities and public agencies of various kinds, have jumped on the notion that such real-time data can provide a picture of the city's functioning useful to its management. The web provides an essential enabling agent in this quest and a range of visual interfaces are rapidly emerging from the 'passive' dashboard that gives an instant picture of what is happening through real-time data feeds to the city to more fully equipped control centres where operators interact more directly in the control of systems whose performance is largely assessed using visualisations from such real-time feeds.

Data is key to these immediate visualisations and, in fact, the smart cities movement in general is dominated by the collection of data in real time and its potential use for real or near real-time control and management. In the next section, we will explore how data is driving the development of infrastructures that are coordinating and integrating diverse urban data but in its most basic form, dashboards and control centres of which individual web sites through which data is organised and visualised are central.

With the emergence of instant access to networks, at the time of writing (August 2014) around 100000 tweets are sent every minute with a total of 7 trillion in 2012, Google receives 2000000 search requests every minute, while users share almost 700000 pieces of content on Facebook (Mashable, 2012). There are upwards of 3.5 billion mobile phone users, some 700 million users of Facebook each month, 120 m Twitter users, 30 m Foursquare, and 46 m Linked-In users (Kearney, 2013). The sheer volumes of data being generated in this way are mind-boggling and as much of this data is without real structure as it is generated as a by-product of the devices used to produce it, there is a massive problem of making sense of it all. The obvious first step is simply to classify it through dashboards that simply take a series of data streams and display the quantities of the data involved with respect to the time over which it is generated. Temporal comparisons are thus the essence of how these dashboards might be used. In Figure 1, we show an associated infographic which collates much of this information together and provides a wider picture of this volume. An increasing amount of this data stream is geo-located, from check-ins via social networks sites like Foursquare through to Tweets and searches via Google Now. The data that cities and individuals emit can be collected and viewed to make it visible, thus aiding our understanding not only of how urban systems operate but opening up the possibility of the continuous real-time viewing of the city at large (Hudson-Smith, 2014). Cities across the world are at various stages of both releasing and utilizing such datasets as both producers and consumers of urban information. It is part of our realization that smart cities are no longer places where city governments act as the top-down drivers of development; rather, they act as one of the players in a much wider ecosystem of data and information

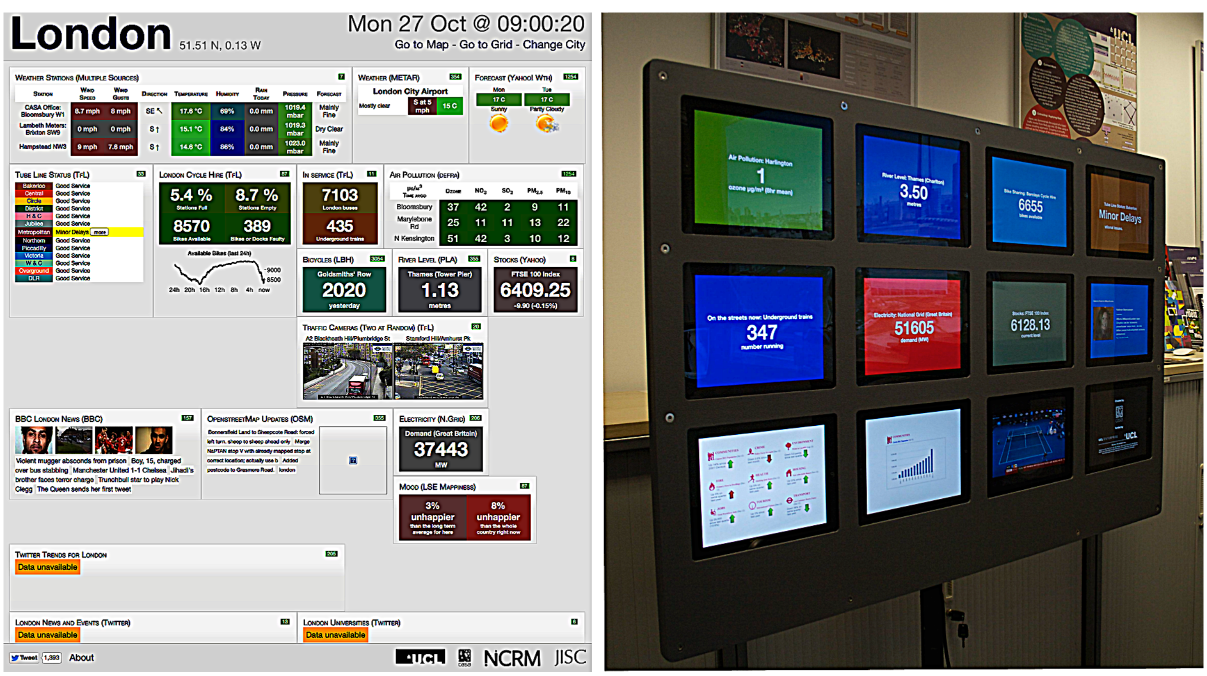
Figure 1. The Dataverse: An infographic summarising the picture in June 2012 (Source: http://mashable.com/2012/06/22/data-created-every-minute/)



A key role that a city government plays in this emerging ecosystem is as a provider of data. The London Data Store is a prime example of how such an archive can provide an impetus to the creation of services and added value from data. Developed by the Greater London Authority and part of the EU **iCity** project, which involves building a platform of linked open applications for innovation in smart cities (http://www.icityproject.eu/), the data store has stimulated over 70 mobile applications linking to more than 500 datasets from a combination of the 27 real-time live traffic and transport data feeds. Through these feeds, we have created a City Dashboard as a means of viewing a key number of live data feeds. This essentially is a dumb interface to a visualisation of these data streams updated in real time, and delivered in a web-based manner. The dashboard collates and simplifies over 20 live feeds from air pollution through to energy demand, river flow, the FTSE 100, the number of buses in service, the status of the subway networks and so on, which we illustrate below in Figure 2 (a).

The dashboard is an early example of collating and visualising data feeds to provide a view of how a city is currently performing. Not only limited to London, the dashboard has also been built for Birmingham, Brighton, Cardiff, Edinburgh, Glasgow, Leeds and Manchester with a version for Venice also under development. But in these different cities, the types of streaming data can be a little different as the dashboard highlights the variability in the availability of feeds from city to city. London, at the present time, is the location for the majority of data feeds with their number updated on a second-by-second basis. The majority of this data is either collected via an Application Programming Interface (API) which is an interface, usually through a web site, where a user can query the status of the system with the

Figure 2. Live Data Feeds (a) Into a Dashboard (b) Disaggregated into an iPad wall (Source: http://citydashboard.org/london/)



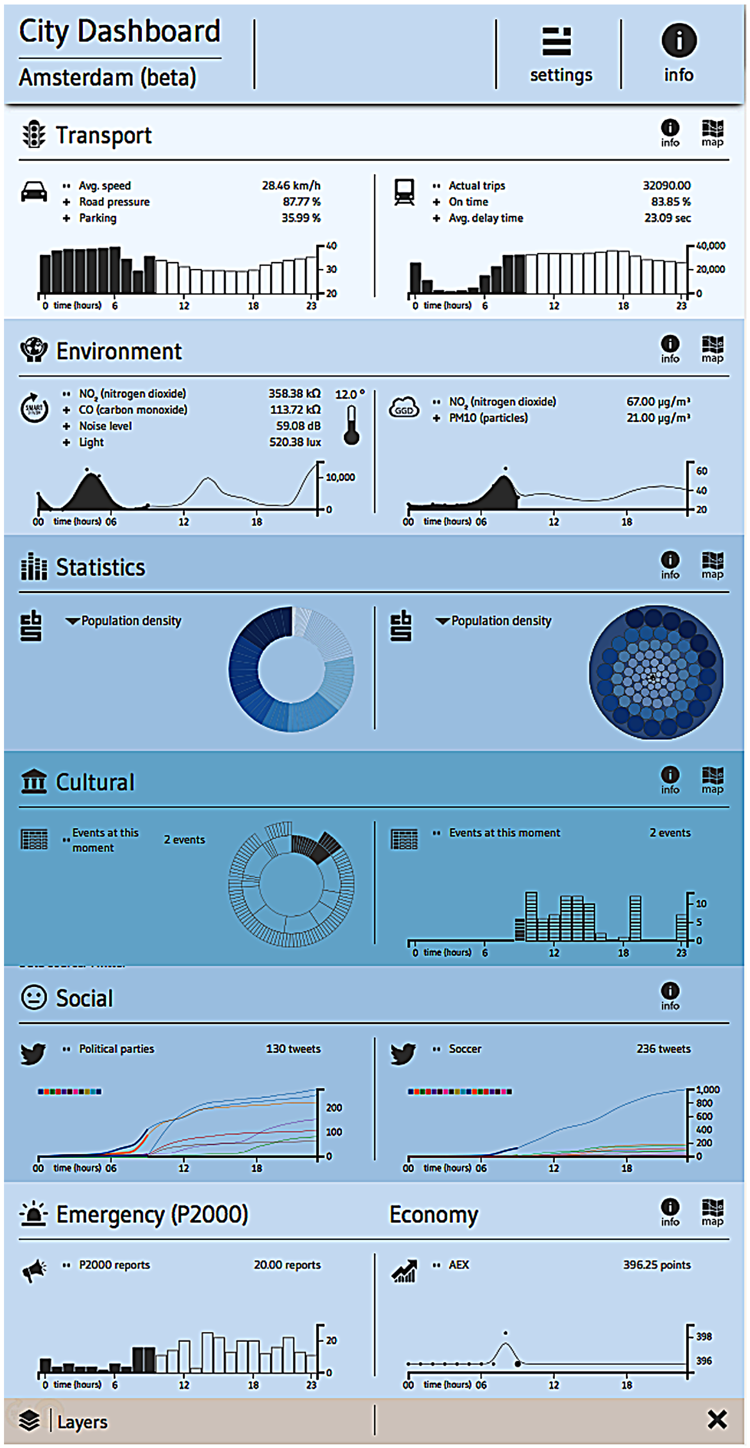
live data delivered to the user (or its client), or the data mined in accordance with a data provider's terms and conditions (O'Brien et al., 2014). The ability to tap into these API feeds allows the city dashboard to provide a view of the particular city at a glance with the use of simple colour coding to indicate the positive or negative connotations of the current state of the data. A custom-made version of the London dashboard has been developed for internal use by the London Mayor's Policy Office at the Greater London Authority. Designed around 12 iPads and mounted into a single system, the board allows each iPad to display historic and live data relating the city as we show in Figure 2(b).

The historic nature of the iPad wall version of the dashboard requires an element of data graphing to examine trends in the feeds, and this has led to the next stage of the development of the **Citydashboard**, moving towards an archive system for city data. At its initial conception, the city dashboard was created as a simple viewer of city-related data feeds. The introduction of basic analytics has created a unified database with over 1 billion rows of data collected at the time of writing. With varying terms and conditions for each of the data streams, it is not however possible to redistribute the historic data. The variety of terms around data redistribution and republishing of feeds has resulted in a city dashboard system built around a custom developed '*cityapi*' that at this moment in time cannot be redistributed. The *cityapi* was produced to simplify the construction of data visualisation, collection and analytics from live feeds with each section of the API relating to specific feeds. The publishing of data streams via systems such as the London Data Store is creating a new landscape in data availability and arguably the development of a new kind of city-wide information system. The ability to refine and redistribute feeds is perhaps the next step to their wider user. While we have focused on the distribution of feeds, it should be noted that it is however possible to view these streams as a new data archive and plug them directly into systems for building various kinds of urban model ranging from simple 2-D and 3-D physical visualisations to mathematical abstractions of urban functions such as traffic, rental values, house prices and so on. Such data has the potential to enable us to develop a series of indicators which measure the performance of the city in both the short- and long-term. Indicators covering aspects of the city from urban flow, such as transport and pedestrian movement, through to a city's economic flows and onwards to more social inputs such as well-being and happiness, are on the horizon. To an extent, all these developments involve analytics that are currently at various stages of development but most are still very primitive and we will thus postpone their discussion until a little later in this chapter.

An example of a dashboard that goes beyond our own physically-orientated data streaming technology is being developed for Amsterdam. This is organised in terms of socio-economic data and is an archive rather than a live stream of outputs. Divided into five sections – transport, environment, population, culture, social-political, sport, security and the economy –it shows trends for these counts over the working day, as in Figure 3. The speed of refresh is hours not seconds and thus this dashboard is more like a state of the nation report.

In fact users can plot the data in mappable form so the dashboard has simple GIS functionality and users can thus get a picture of how these categories are changing spatially across the city, which is divided into 50 or more small zones. In a sense, this implies what might be possible in the not-too-distant future as new sources of open data come on stream, such as house prices, rent, migration statistics and so on, which potentially might be delivered and updated on a day-by-day basis or at least a cycle which is much shorter than the typical year, approaching the second-by-second focus on dashboards based on streamed physical data. In fact, dashboards merge into more formalised control centres where there is more interactive usage and where operators are employed with a

Figure 3. The Amsterdam Dashboard as a living archive (Source: http://citydashboard.waag.org/)



mandate to control various systems which take the real-time feeds from these various systems and employ simple functionality to make key decisions. These have been available for many years for real-time traffic control and currently there are many new systems being developed, the poster-child of which is the IBM system for Rio-de-Janeiro. To date, the analytics associated with such systems are quite rudimentary, largely indicators that are derived directly from raw data (Kitchin, 2014b), and the degree of intelligence or smartness embodied in such systems is not particularly advanced on traditional intuitive responses to crises that have been used for a long time. As we get a better sense of how all these real-time systems interact with one another then doubtless these control centres will improve, but currently the smartness which is potentially associated with such technologies is in its infancy. In fact, their smartness is largely based on the smartness of their users.

SMART DATA INFRASTRUCTURES

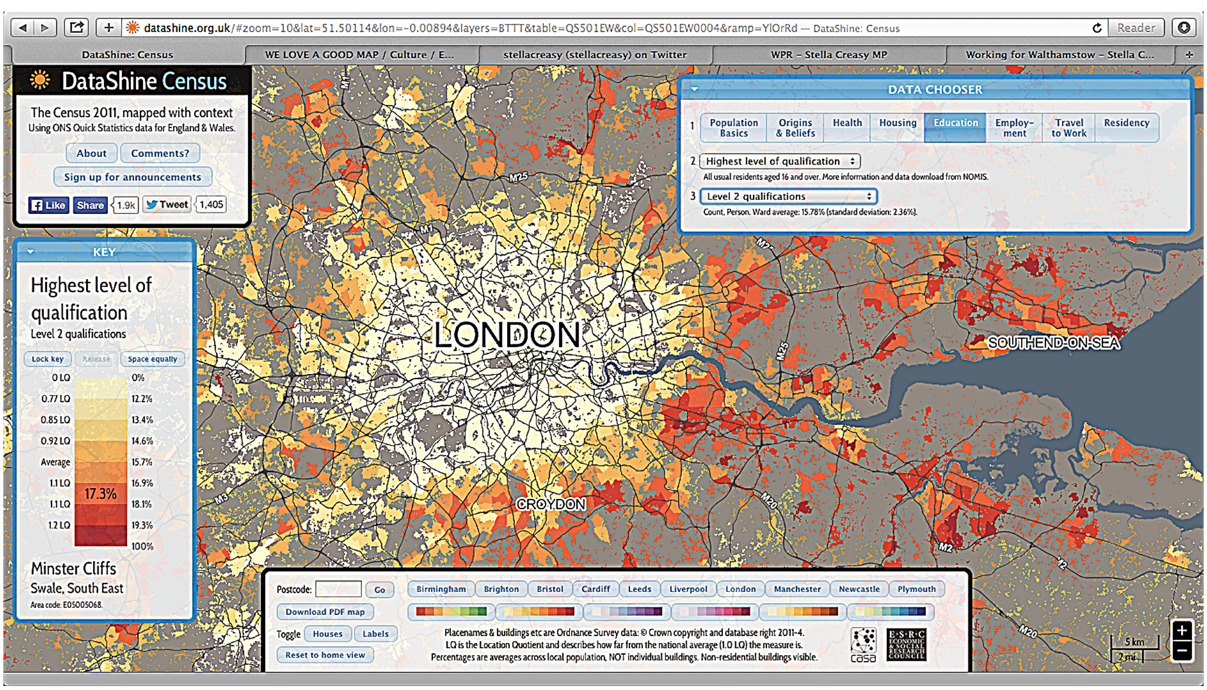
Kitchin (2014a) makes the point that the smart cities movement is as much about data infrastructures as it is about data. It is about how systems are designed that capture, process, and deliver data through various kinds of visualisation and then the construction of analytics – methods and models – that turn this data into information that can be used to predict and then control the system(s) of interest. So far, there is not much infrastructure that stitches together data that is captured in real time, largely due to the fact that the data sources are not coordinated and have no common keys for their integration. A good example involves transit data in London where demand for travel is logged in real time through the smart card system which 85% of travellers on public transport – bus, tube and light rail, and heavy overground suburban rail – use in payment for the service. This data is captured when travellers tap in and out on the tube and rail and tap in on the bus. There is an immediate problem of linking bus data to tube data; although it is possible to construct journeys using rail then bus using simple analytics, it is hard to predict user trips that use bus then rail because there is no tap out on bus. In short, these two closely related data sources cannot be easily collated. The system also records the position and time and status of any bus and train through APIs which deliver that data to any user with a three-minute latency but it is impossible, without some very brave assumptions, to link this supply data to demand data from the smart card. The missing data relates to the time and position when a traveller gets on and off a train and this data, which is within the complex network of underground stations, is simply not available. Moreover, assumptions need to be made about what trains travellers get on as there are many combinations of routes that fulfil the same travel objectives. Our point here is that despite there being very good data from these real-time feeds, it is impossible to construct a portal that integrates this data so that the trip system can be studied in its entirety. Of course it goes without saying that this data cannot be linked to demographic and related attributes and thus it is not possible to generate analytics that would help us understand how demand might be changing.

Building portals which introduce structure into data is a major quest in developing protocols and analytics that let both users and planners of the smart city function more intelligently. Since the web was developed during the last 20 years, geospatial data has become central and the first systems with widespread use dating back to the mid 1990s were map interfaces providing simple animation. Google maps is now 10 years old and it has become the *de facto* standard with usage figures in the order of one billion users each month, although this figure is complicated by repeat users and different ways in which these maps are interfaced in various portals. To date, the best data infrastructures developed which pertain to smart cities are those that deal with the less routine but regular and well-organised tranches of public data that inform us how cities function, in particular population census data. A good example of the kind of portal that takes state-of-the-art visualisation techniques and uses them to display, query and construct simple indicators of geospatial data is the **DataShine** 2001 Census portal developed by O'Brien and Cheshire (see http://datashine.org.uk/), which enables users to pull up and query a very wide variety of map data across many spatial scales pertaining to characteristics of the population built at the finest scale available for the UK.

In fact, although portals such as **DataShine** could be constructed with access to the raw data or semi-processed archives available as open data from various agencies such as the ONS, NOMIS and OS[2] in the UK, it is much easier and cleaner to download the data and organise it for rapid access. In **DataShine**, bulk data downloads from NOMIS are stitched together and then placed in a PostgreSQL database. The map base is taken from OS Open Data and thus the portal builds on several public data sources that have recently become more easily available through the open data movement. The typical interface is shown in Figure 4 where the population with educational level 2 skills is displayed at the scale of Greater London. Users can zoom in and out very rapidly and it is easy to get a picture of the whole nation (at least England and Wales, which is the current implementation) in this manner.

The interface is organized so that as much data as possible is displayed on the screen, while users can move the windows around and the ultimate map can be downloaded as a PDF at a higher level of resolution than the screen display. The colour spectrum can be changed on the fly and in this way users can explore the data in a remarkably flexible manner producing exactly what they require with ease. Of course, all data exploration and queries demand a degree of ingenuity but **DataShine** is an example of a portal that is immediately useful

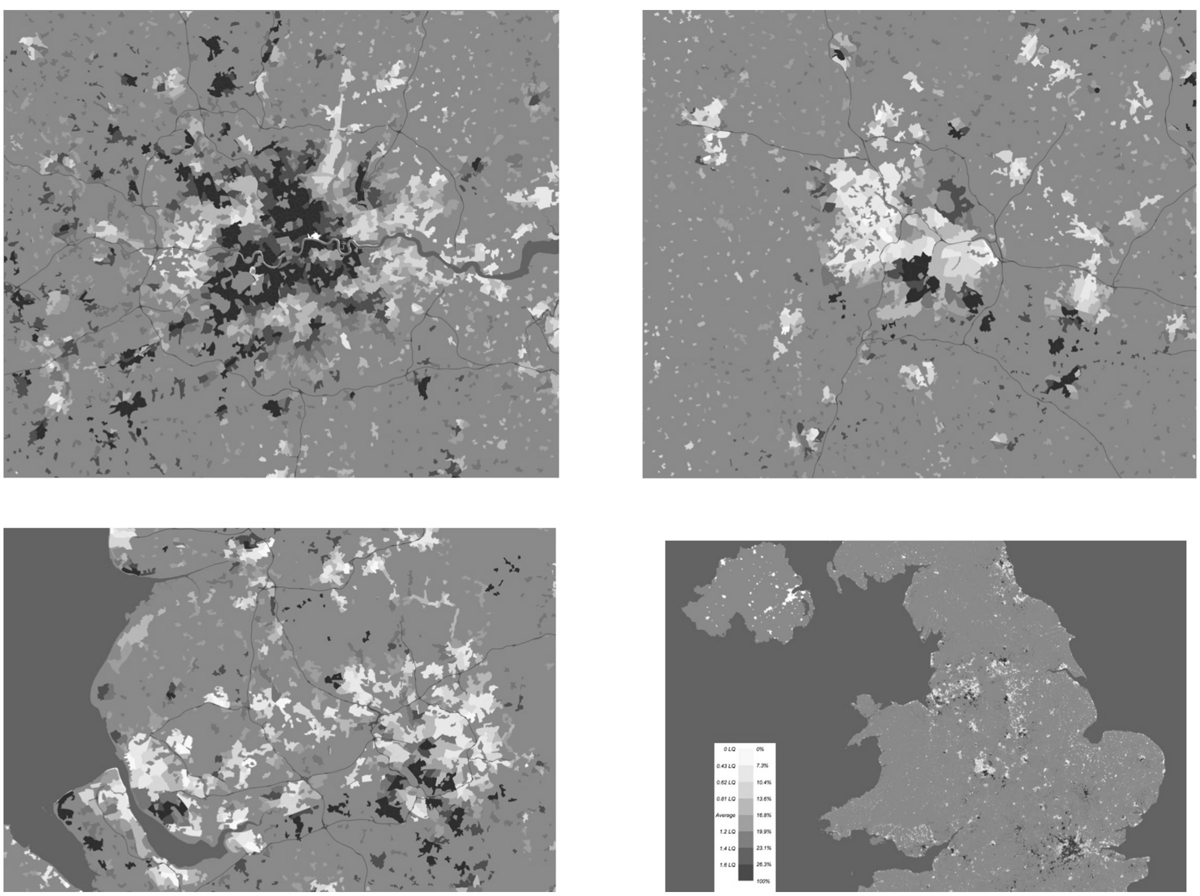
Figure 4. The DataShine Portal for the 2011 population census



for those involved in understanding the variation in different attributes of the population and their relation to policy. The system is also able to produce excellent graphics for research purposes and in Figure 5 we show how we can generate a series of maps at different scales that reflect how the morphology of cities at these scales is reflected by a population attribute based on the percentage of professional occupations by ward.

A good deal of analysis using geospatial data is now being included in web-based GIS and there are portals emerging which enable users to create their own maps, uploading data in standard formats such as shapefiles, XML formats and so on, and then manipulating and merging data in various ways to enhance their analysis. Our own portal, called **MapTube,** which is billed as a 'Place for Maps', has been under development for several years and acts as a workhorse for simple map analysis and storage. When users are able to use web software which is entirely open in the way **MapTube** is, we need to guard against violations of copyright. To this end, **MapTube** creates maps for the users from their own data, delivers the map to their web site and then keeps a pointer to the site so that the user retains or is responsible for any copyright. In fact, **MapTube** mainly contains maps that we have created and for it to gain widespread use we need to broadcast its availability. The fact that portals such as these

Figure 5. Visualisations of the distribution of professional and managerial occupations in the biggest cities in England and Wales from the DataShine Portal. Going clockwise: Greater London; Birmingham; Liverpool and Manchester; England and Wales.

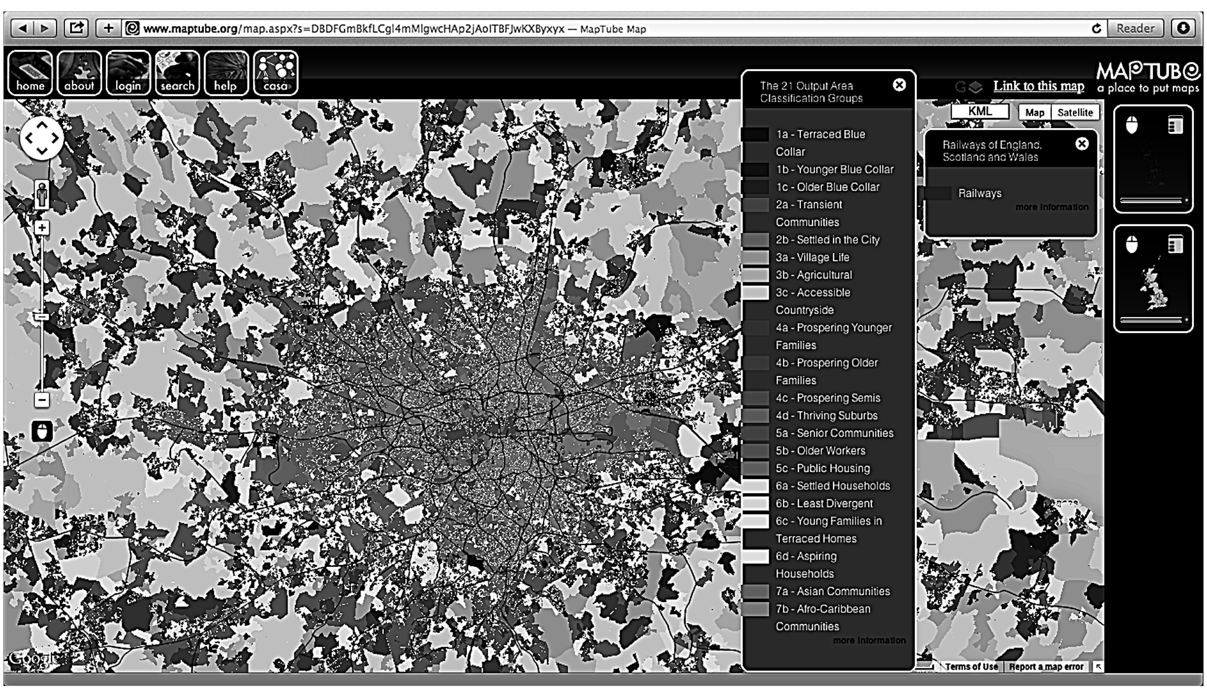


are queried and accessed many thousands of times does not imply widespread usage for there is still a learning curve and the number of professionals dealing with data that pertains to smart cities is still quite small. Most municipalities, for example, still do not have the professional capabilities to deal with smart city technologies of which big data and web interaction are key, and thus there is a growing gap between data analysis and the kind of urban analytics that portals like **DataShine** and **MapTube** offer, despite the fact that they are fairly basic.

We show the interface to the **MapTube** site (http://www.maptube.org/) in Figure 6 where the user is able to access various parts of the site that let them upload their map (with quite straightforward help facilities), display it and then merge it through overlay with any other map that is on the system. As many overlays of different maps as the users wishes can be created with transparency-fading facilities so that spatial correlations and comparisons can be made. In Figure 6 we show the geodemographic structure of the population of Greater London as the output area classification (OAC), which takes the various indices and profile of the population in each ward and then produces a summary of this according to various social and economic descriptors. We also overlay railway lines on this map so that the user can make sense of any radial or circumferential bias in the spatial distribution of population types. In this way, a user can build up a picture of a place. In both **DataShine** and **MapTube**, users can dig down and pull up the raw data thereby having full control over any understanding that can be gleaned from this kind of casual spatial analysis.

What we have shown so far are somewhat straightforward but robust portals to data that pertains to the spatial distribution of various functions in the city. The common mode of integration is spatial where the common key is the geocode. It has taken 20 years or more to reach the stage where portals such as these are now widely available to inform urban analysis, and more integrated

Figure 6. A typical MapTube interface displaying OAC data



systems have been slow in coming. The scale of hyperbole in this domain is enormous with many proposals for integrated systems that are simply not possible. With unstructured data and few common keys, integrated systems that merge many different streams of data are rare and in any case, in terms of data delivered in real time, there are often no strong reasons why such data should be integrated. In fact, it is more likely that the device itself acts as the integrator or platform on which many applications can be developed, and it is the user who will perform any integration with the device acting as its own portal to many different kinds of data.

There is another important reason why integrated data portals will also remain the exception rather than the rule. Cities are built from the bottom up, being the product of countless decisions that are made individually, even if within a social context. Their structure is one of self-organisation and there is little reason to think that millions of people making decisions about how to develop and use new information technologies will self organise in any different way. In fact, the development of computing has followed a similar path to all other human endeavours with surprising twists and turns, and the notion of top-down coordinated systems that function perfectly is fanciful. In fact, systems need to be designed so that they are able to accept and deal with error and this usually requires human intervention. Of course, some transaction processing systems dealing with highly routinised data such as automated banking, the control of automated vehicles such as trains, the control of energy in home environments and such like are capable of being highly centralised and operated accordingly. But in general most of the functions that characterise the contemporary city require a mix of automation and human decision making to enable their successful functioning and the kind of urban ecology that is resulting – that is, the urban ecology that we might call the smart city – is just that: it is an ecology which situates organisms in their environment, structured so that it maintains diversity and resilience to various changes that optimise its functioning.

DATA STREAMS FROM SOCIAL MEDIA

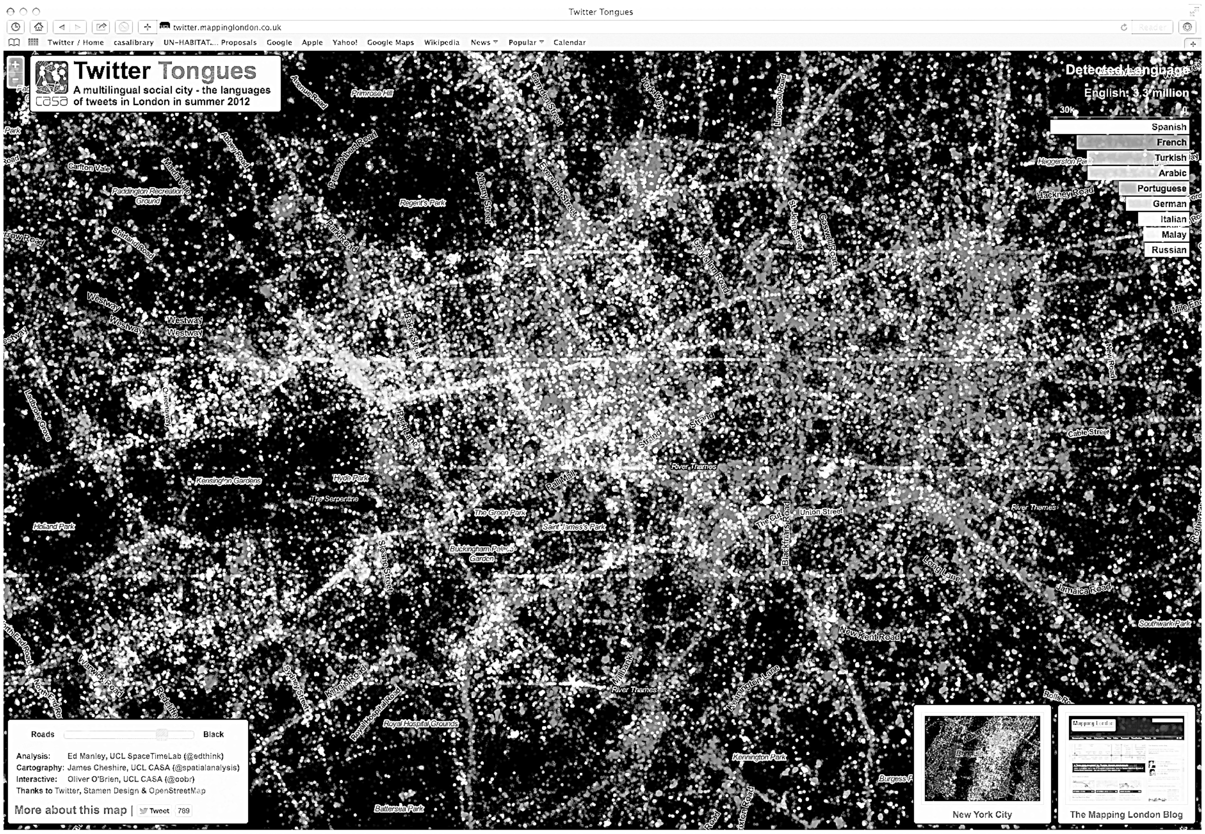
Here we will define social media as any kind of medium through which individuals communicate with one another in space and time. To an extent, this defines the city itself for as everyone from Plato to Jane Jacobs (1961) has argued, cities are places where people come together to improve their quality of life through communication which leads to the sharing and pooling of their talents. As cities evolve from the bottom up with their subsystems continuing to function as they grow, traditionally they are best articulated in terms of distinct communities or neighbourhoods which are arranged in hierarchical order with this hierarchy elaborating itself as a city scales in size. In the last 100 years, onto this pattern have come new ways of interacting and communicating in which the role of physical distance has been tempered and, in some way, by-passed through the telegraph, telephone, television and so on. Most of these media have been passive or at least interactive in a modest way, but with the rise of the net, the web, and our ability to connect up using portable/mobile devices there has been a veritable explosion in new ways of interactive communications. Their impact on the ways we behave in cities with respect to one another is not at all clear. As these new forms of communication work themselves out, we are increasingly able to record and archive these new forms of interaction and the quest is to now to consider the ways in which this media is improving the quality of urban life or otherwise. Moreover, such communications are having an impact on the form of the city and are certainly changing the way we travel in physical terms. We are at the beginning of a revolution in the way cities are structured with new patterns of communication layered on top and alongside traditional ones, and the impact on where we locate and how we travel is becoming ever more complex.

So far, the most serious attempts at exploring these new media have been through access to mobile phone calls, which have the prospect of revealing all kinds of communication, from social networks to travel patterns. CDTs usually contain geocoded information that logs the origin and destination of the call and judicious analysis of the time and length of calls can provide some probability of the call being of a particular type. If attribute data about the user is available from the mobile phone provider (which it usually isn't because of confidentiality and/or commercial reasons) then an even better prediction of what the mobile phone call relates to can be generated. This is about as good as it gets and in cases where this level of data is available, there is the possibility that such data might be used as a 'proxy' for travel and interaction. However, this new data would appear to be most useful as a complement to existing travel data of the conventional kind. When it comes to recreational usage, such as short text messaging, then the big problem is that only a very small proportion of such messages are tagged to location and an even smaller number can be related to an origin and a destination. The content of such messages is problematic because they are short and cryptic and although these data sets can be enormous – we noted above that there are more than 150 million tweets per day globally – the usable content is tiny. When it comes to other social media sites, such as Foursquare and Facebook, the problems multiply because the use of such media is much less obvious in terms of the physical space in which such communications take place.

The attraction of working with these new types of social media is that they contain data at the individual level which can be aggregated to search for patterns and correlations, and they are usually coded at a very fine level of space – coordinates, for example, or the finest level of zip code – and at temporal frequencies of minutes or even seconds. A picture of the city evolving in the very short term can thus be assembled if the data is judged to have any relevance whatsoever. A good example of this data is the pattern of ethnicity in a large city – London in this case – which is extracted from an analysis of geo-located tweets with respect to the language used. This has been mined and displayed by Cheshire and Manley (2012) and Figure 7 displays the pattern that they extracted for Greater London over 5 summer months from May until September of 2012 (covering the Olympic Games weeks). This is based on 3.3 million usable tweets from the 6 million or so which gave a GPS location. In fact, during this period there were more than 300 million tweets in London but only 1% of these appear to have a GPS location and thus the sample is hardly representative (Betanews, 2012). In fact, this map betrays the basic problem with social media and the possibility of generating useful and informative data from it that can say something about the smart city. The problem relates more widely to mobile phone data where very often the data available is only from one provider and in most cases the market for mobile phones is partitioned between two or more providers. Thus the data can be highly biased and, in the case of Twitter usage, it is also very clear that when we take age into account the bias is greatly exacerbated as it is widely known that the number of Twitter users declines precipitously with age, for example.

In Figure 7, the scale of the illustration blurs the colours somewhat and it is necessary to zoom in and manipulate the transparency of the map to get a good understanding of the clustering. It is also worth noting that when writing about visualisation in the smart city, we are not able to show the diverse range of visualisation tools that are possible because they depend on animating maps and related infographics; for this readers must turn directly to the web or to archived videos such as those on *YouTube*. Nonetheless, the pattern

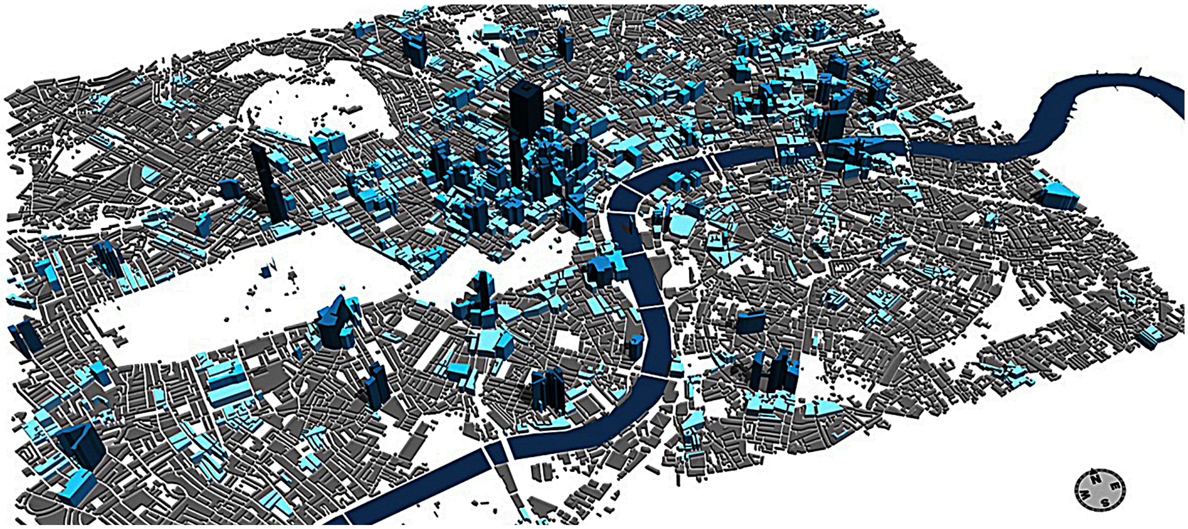
Figure 7. Geolocated tweets in central and inner London mined according to language using Google Translate and collected in the summer of 2012



generated in the static map in Figure 7 is similar to that pertaining to the various ethnic group clusters that have been provided in the Output Area Classification (OAC) (http://ukdataexplorer.com/census/).

Many digital methods and models have been derived in parallel to the smart city movement in that the focus is on the longer-term analysis of factors affecting a city's economy, demography, transportation systems and so on. Iconic models, which are 3-D representations of the city in digital form, and more abstract mathematical models, which attempt to predict the location and interaction between different land uses and activities, are being slowly informed by new data that originates from shorter term real-time feeds such as those associated with mobile phones, smart cards, and various sensors embedded in places of continuous activity. Some of the tools used for visualisation in 2-D from GIS and 3-D from computer-aided design are now being used to visualise real-time streamed data such as Twitter feeds. One of our projects takes geolocated tweets and associates them with specific locations which can be identified as land and building parcels, as we show in Figure 8. By placing this data into a procedural system, the 'Tweet City' project is an ongoing visualisation which utilizes the Twitter API in an attempt to create a new 3-D urban landscape. In addition, the project augments already existing GIS spatial data with real-time Twitter feeds using a custom-developed 'tagging' methodology.

Figure 8. Live Twitter feeds in London visualized as building heights



This allows the user not only to develop different visualizations by editing simple rules but also to develop more sophisticated types of analysis based around city data feeds.

This visualisation, in fact, makes use of an augmented 3-D GIS called **City Engine** which embodies a procedural modelling system that lets the user associate given rules for the development of each object in the GIS. The key advantage of moving city data feeds into a procedural geographic information system is the ability to introduce more advanced spatial analysis functions within real-time data mining. The project aims to include multiple feeds, such as air-quality readings, by tracking down enough air-quality sensors to form accurate, pinpoint pollution estimates. The system operates online and, as it is linked to a 3-D representation of the city, has the potential to augment the **Citydashboard** concept towards one of integrating wider feeds such as those being explored in **iCity**. Emerging trends can be visualised on a city-wide or hyper-local scale via the move to a 3-D interface. Moving to a more 'urban' view of the data and placing it in a geo-located position, whilst still maintaining the real-time reporting, further develops the concept. Tweet City developed by Flora Roumpani and Stephan Hugel can be downloaded at http://urschrei.github.io/CityEngine-Twitter/ where the user can engage in various explorations of the data and its visualisation.

Our last visualisation involves generating big data in quite a different way by sampling the 'crowd' eliciting responses to various events which can be captured and imported into visual models that let users and analysts explore the movement of crowds in motion. This is not quite crowdsourcing in the traditional way but it is sampling data pertaining to live scenes and then augmenting their analysis though visual models of the kind that are available using **City Engine**. An increasing number of urban information systems which can be visualised in 2-D or 3-D form rely on variants of crowd-sourcing for their data through a form of citizen science. As Haklay (2010) states, "… using citizen science can take a form in which volunteers put their efforts to a purely scientific endeavour, such as mapping galaxies, or a different form that might be termed 'community science' in which scientific measurements and analysis are carried out by members of local communities so they can develop an evidence base and set action plans to deal with problems in their area". With almost ubiquitous mobile phone ownership in urban areas, 'the crowd' is becoming both a provider and user of data. Many crowd-sourced applications are still at the prototype stage but with the ability to ask a crowd to share their location as they move across a city, and this has core implications for urban monitoring and management.

Figure 9 details a live capture of crowd-sourced location data during the Lord Mayor's Show in the City of London in 2011. The aggregated data of all participating visitors – those who line the route of the parade – is used to create a real-time overview of the crowd density at the event locations. Organizers can subsequently use the system's output to identify potential hot spots before they turn into hazards. Situations can thus be defused by sending visitors location-based advice either via a push notification or SMS text (SIS, 2013). In fact, taking this visualisation into a real-time context is difficult as restrictions on bandwidth will remain critical for a long time to come as yet in capturing and transmitting data back to users with no appreciable lag.

Another feature of the smart city in terms of our definition as self-monitoring, analysis and reporting is volunteered location-sharing. This is similar in nature to adding location to a social network; it allows a new generation of data-miners and data scientists to collect and map location, expanding the view of how we not only use space and place but through additional information as to how we perceive space. The measurement of happiness, emotions and well-being in space is an emerging field but one that is perhaps central to the concept of a self-monitoring, analysing and reporting city. One example is the LSE 'Mappiness' project which is an iPhone application that asks users at random points during the day the extent to which they are feeling happy (http://www.mappiness.org.uk). The application associates each response with key spatial and environmental indicators using the GPS location data. As MacKerron and Mourato (2013) state, they can calculate the habitat type at each reported point location which they then classify in the nine broad habitat categories used in the UK National Ecosystem. Using data from Weather Underground, which collates data from

Figure 9. Mapping the crowd and visualising its density in city engine

280 weather sensors across the UK, they link each response with weather conditions reported by the station nearest to the response location at the moment nearest the response timestamp. They also calculate whether it was daylight at the response date, time and location. Finally, the application allows the user to record a sample of sound and to take a picture of their location. The application has over 3 million users and is an example of extracting new sources of information using mobile devices. The mapping of emotions opens up our ability to explore how we actually feel about our built environment. Applications such as Mappiness are, of course, subjective, yet represent a new type of self reporting tool for the inhabitants of the city. It is these new sources of data, combined with the perhaps more traditional datasets, that hold the key to the development of a smart city. A city where the current status quo can be monitored and fed into urban models to develop a predictive view of the future of a city system.

THE FUTURE OF SMART CITIES AND THE NEW URBAN ANALYTICS

In this chapter, we have taken a relatively low key approach to smart cities in terms of the new urban analytics that are being composed to ensure that better analysis, policy-making and ultimately a better quality of life contribute to the outcomes that the smart city is able to generate. Our focus has been on new data sets that provide the context for new forms of understanding and we have not focused on the tools – the simulation models and methods – that might be used to articulate this understanding, and articulate new modes of control and management. These analytics loosely form part of what many call ‘urban informatics’, which is defined as the application of computers to the functioning of cities; Foth et al. (2011), for example, define urban informatics as the study, design, and practice of urban experiences across different urban contexts that are created by new opportunities of real time, ubiquitous technology and the augmentation that mediates the physical and digital layers of people networks and urban infrastructures. This is strictly the narrower focus that we have adopted here; it pertains to the ways in which computers are being embedded into cities as hardware and software so that routine functions can be made more efficient, not only through automated responses but through the data that such computation generates, which is central to policy analysis. This narrow focus is on control and the kinds of analytics that would best pertain to this area are models that deal with rapid movements and location in cities that occur in almost real time. In its wider focus, it is concerned with the use of computers and communications to enable services to be delivered across many domains and to enable populations to engage and interact in policy issues that require citizen participation. Urban informatics is thus intimately tied up with monitoring, analysis, reporting and thence control and management, which are the key elements that we have used in this perspective on the smart city.

The kinds of analytics that now form the cutting edge in realising smart city technologies are not new. Half a century ago, after the rise of operations research, which involved the applications of mathematical and statistical tools to search for patterns and to optimise the organisation of industrial and military systems, the tools involved in optimising short-term resource allocations using various kinds of queuing theory, optimisation such as linear programming, scheduling systems based on graphs and path analysis, were applied to routine functions in cities, particular police, fire and related emergency services. Urban operations research, as this came to be called (Larson & Odoni, 1981), was quite widely applied in urban contexts in the US as we indicated earlier and some of these tools have remained embedded in the routine functions of these services. In fact, as we also implied, although these kinds of tools deal with quite well-defined protocols, their application over the last few decades has not been a roaring success and their interaction with the political and bureaucratic process has been problematic. This poses a stark warning for the smart cities movement, and although this is not the place to discuss these wider issues, they are important (Batty, 2014). Here we will conclude with a short summary of the kinds of technologies that lie at the basis of new urban analytics, as these are rapidly developing at the present time and there are many opportunities as well as pitfalls.

The range of analytics that pertain to the kinds of data that we have reviewed here is wide in that it ranges from statistical methods that seek to extract patterns in such data to simulation models that are validated to such data and thence used for prediction. Prescriptive or design methods also map onto these analytics to an extent, the new class of geodesign methods emerging from GIS being a case in point. These analytics are also surrounded by various minimalist tools which relate to the extraction of indicators and performance measures from data, such as those that are implied in data streamed into dashboards and control centres and then transformed into measures useful in providing users and policy makers with some sense of how the city is performing relative to various baselines. There is now a wide class of multivariate methods that fall under the rubric of data mining tools that are sometimes referred to as machine learning. These range from basic component and factor analysis, which have been around for 50 years, to newer techniques such as neural networks and evolutionary algorithms that extract patterns in large data sets by learning through iterative exploration. These techniques tend to be non-causal in focus: they work by extracting correlations and some, such as Anderson (2007), have gone so far as to argue that the search for causal relationships is a thing of the past in the age of big data and data mining. But we, amongst others, would consider this a controversial stance, born of a lack of understating of the complexity of cities. It may be relevant in some contexts where routine patterns are dominant and unvarying but it is unlikely to be the case in searching for ways in which to understand and control systems as complex as the city.

Important elements in this range of tools are large-scale integrated models of various kinds. To an extent, these tend to be developed for longer-term, more intricate aspects of city systems which do not focus on the sorts of cybernetic control that short-term analytics for the management of energy and transit relate to. This makes it important to see the smart city in a somewhat wider context than we have emphasised here. A more complete review of analytics, data and visualisation would cover these kinds of model where the definition of the system of interest is more ambiguous and unclear than in the kinds of routine system developed here. This needs more comprehensive review but it is important to conclude this chapter by noting that the term 'smart cities' is being used to cover a very wide range of spatial and temporal scales. These cover a range of processes relating to how cities function and it is important to be aware that the tools being developed cut across these scales, being developed in ways that make their usage and relevance quite different between different types of application. In fact, our vision for urban analytics is extremely diffuse in that there is a deep hierarchy of tools that are being slowly fashioned to deal with many different aspects of urban systems. Such technologies thus need to be finely adapted to the many different perspectives on the smart city which now exist while being focussed on the many different policy (and political) contexts which dominate all discussions about future cities.

ACKNOWLEDGMENT

Thanks to Steven Gray, James Cheshire, Ed Manley, Richard Milton, and Oliver O'Brien whose examples of map technologies we have included here. This chapter was part financed by the ESRC Talisman Project ES/I025634/1.

REFERENCES

Anderson, C. (2007). The End of Theory: Will the Data Deluge Make the Scientific Method Obsolete? *Wired Magazine*. Retrieved from http://www.wired.com/science/discoveries/magazine/16-07/pb_theory

Batty, M. (1997). The Computable City. *International Planning Studies, 2*, 155-173. Retrieved from https://web.archive.org/web/19980124005925/http://www.geog.buffalo.edu/Geo666/batty/melbourne.html

Batty, M. (2013). Big Data, Smart Cities, and City Planning. *Dialogues in Human Geography*, *3*(3), 274–279. doi:10.1177/2043820613513390

Batty, M. (2014). *The Smart Cities Movement, forthcoming CASA working papers series*. London: UCL.

Batty, M., Axhausen, K., Fosca, G., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., & Portugali, Y. et al. (2012). Smart Cities of the Future. *The European Physical Journal. Special Topics*, *214*(1), 481–518. doi:10.1140/epjst/e2012-01703-3

Betanews. (2012). *Twitter: 500 million accounts, billions of tweets, and less than one percent use their location*. Retrieved from http://betanews.com/2012/07/31/twitter-500-million-accounts-billions-of-tweets-and-less-than-one-percent-use-their-location/

Cheshire, J. A., & Manley, E. (2012). *Twitter Tongues*. Retrieved from http://twitter.mappinglondon.co.uk

Flood, J. (2011). *The Fires: How a Computer Formula, Big Ideas, and the Best of Intentions Burned Down New York City and Determined the Future of Cities*. New York, NY: Riverhead Trade.

Foth, M., Choi, J. H., & Satchell, C. (2011). Urban Informatics. *In Proceedings of the ACM Conference on Computer Supported Cooperative Work* (pp. 1-8).

Greenfield, A. (2013). *Against the Smart City. Amazon Media Kindle*. New York, NY: Do Projects.

Haklay, M. (2010). Geographical Citizen Science – Clash of Cultures and New Opportunities. In *Proceedings of Workshop on the Role of Volunteered Geographic Information in Advancing Science*. Retrieved from http://web.ornl.gov/sci/gist/workshops/2010/papers/Haklay.pdf

Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*(3859), 1243–1248. doi:10.1126/science.162.3859.1243 PMID:5699198

Harrison, C., & Abbott-Donnelly, I. (2011). A Theory of Smart Cities, Annual Meeting of the ISSS. Retrieved from http://journals.isss.org/index.php/proceedings55th/article/viewFile/1703/572

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. *IBM Journal of Research and Development*, *54*(4), 1–16. doi:10.1147/JRD.2010.2048257

Hudson-Smith, A. (2014). Tracking, Tagging and Scanning the City. *Architectural Design*, *84*(1), 40–47. doi:10.1002/ad.1700

Jacobs, J. (1961). *The Death and Life of Great American Cities*. New York: Random House.

Kearney, A. T. (2013). The Mobile Economy 2013. Retrieved from http://www.gsmamobileeconomy.com/GSMA%20Mobile%20Economy%202013.pdf

Kitchin, R. (2014a). *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences*. London: Sage. doi:10.4135/9781473909472

Kitchin, R. (2014b). *Knowing and Governing Cities Through Urban Indicators, City Benchmarking and Real-Time Dashboards*. Retrieved from https://www.maynoothuniversity.ie/progcity/

Larson, R. G., & Odoni, A. R. (1981). *Urban Operations Research*. NJ: Prentice-Hall.

MacKerron, G., & Mourato, S. (2013). Happiness is Greater in Natural Environments. *Journal of Global Environmental Change*, *23*(5), 992–1000. doi:10.1016/j.gloenvcha.2013.03.010

Mashable. (2012). *How Much Data is Created Every Minute?* Retrieved from http://mashable.com/2012/06/22/data-created-every-minute/

Negroponte, N. (1995). *Being Digital. New York, NY*. Alfred: Knopf.

O'Brien, O., Batty, M., Gray, S., Cheshire, J., & Hudson-Smith, A. (2014). On City Dashboards and Data Stores. In *Proceedings of Workshop on Big Data and Urban Informatics*. University of Illinois at Chicago, Chicago, IL.

SIS. (2013). *Mapping the Crowd, The Lord Mayors Show, SIS Software*. Retrieved from http://www.sis.software.co.uk/

Sterling, B. (2005). *Shaping Things*. Cambridge, MA: MIT Press.

KEY TERMS AND DEFINITIONS

Crowd-Sourcing: Sampling a population with respect to their opinions using internet-related technologies such as web questionnaires.

Data Infrastructures: Combinations of hardware, software, dataware and organisational-ware that provide the structures that deliver data and make it computable.

Map Portals: Web-sites and/or standalone software systems that enable users to display, query, locate and visualise spatial data in map form as layers.

Social Media: Digital media that pertains to social interactions between people and places such as short text messages and web-based social networking sites.

Urban Analytics: Methods of mathematical and symbolic modelling that generate insights into existing data as well as predictions of future data.

Urban Dashboards: Portals, usually web-enabled, that collate continuous feeds of data which are produced in real time.

Visualisation: Methods of turning data and analysis into images that can be near real such as 2D maps and 3D scenes as well as more abstract such as networks and graphs.

ENDNOTES

1 The adjective 'smart' in this context is a peculiarly American term. It was first used in an urban context with respect to urban growth. 'Smart growth' evolved as a term for managed urban sprawl in the 1980s and 1990s (http://www.smartgrowthamerica.org/) and its usage in IT applied to cities – smart cities – was an obvious extension (Batty et al., 2012). Earlier definitions, from wired cities to information cities, intelligent cities, digital cities and virtual cities, cover the same domain tending to merge into one another but all covering the wider context. The term 'smart' is much more widely used in American everyday language than British everyday language, but it is rapidly being adopted globally.

2 **ONS**: Office of National Statistics; **NOMIS**: National Online Manpower Information System; **OS**: Ordnance Survey.

Chapter 17
From the Smart City to the People-Friendly City:
Usability of Tools and Data in Urban Planning

Giulia Melis
SiTI Istituto Superiore sui Sistemi Territoriali per l'Innovazione, Italy

Elena Masala
SiTI Istituto Superiore sui Sistemi Territoriali per l'Innovazione, Italy

Matteo Tabasso
SiTI Istituto Superiore sui Sistemi Territoriali per l'Innovazione, Italy

ABSTRACT

This chapter addresses the smart city concept as a first step towards the formulation of a new socially-improved urban concept which may be defined as that of the "people-friendly city". This new task involves the employment of IT tools, but using new methods and pursuing different goals other than mere numerical information. In terms of the urban environment, this means that cities should be designed for people, and planning practitioners should be able to understand citizens' needs, communicate with them and involve them in a collaborative process. Therefore, an overview of the implications of smart cities for urban planning is followed by a more detailed analysis of Planning Support Systems (PSS) as innovative tools for enhancing the process of delivering a more inclusive and people-friendly urban environment. The lessons learnt from the application of the PSS tool is then illustrated in order to define the potentialities and key points for the development of similar tools.

INTRODUCTION

Over the last few years, the rapid development of Information Technologies (IT) has created new opportunities for the sustainable growth of cities. Nowadays, cities are being approached as complex systems which increasingly attract people who wish to work and live in them. For this reason, cities have to deal with various problems, such as traffic congestion, noise and air pollution, energy efficiency, high densities, the lack of green space and an increasing demand for services. In

DOI: 10.4018/978-1-4666-8282-5.ch017

this context, IT can provide strong support and enable a scientific approach to the management and planning of urban areas to be adopted. Sensors and digital-control technologies can gather data from citizens' behaviour and provide a new way of reading the workings of the city system, therefore transforming the city into an "open-air computer" (Biderman, 2013) that automatically collects and calculates data. This new integration of IT in urban areas has generated the concept of "smart city".

Consequently, smart cities are based on a wide range of information tools to be used in urban contexts. This opens up new frontiers in the study of city systems, although it also generates certain fresh obstacles to understanding the real reasons behind the human need to live in cities. First of all, the computerized quantitative approach clashes with the social and qualitative origins of urban co-living. Secondly, until now tools have mainly been employed to gather data rather than to provide real applications aimed at improving the Quality of Life (QoL) of citizens. Cities are full of video-cameras and sensors constantly collecting data that can be rarely used by citizens to improve their own quality of life.

As a result, citizens are a long way off benefitting from the utilization of smart technologies in urban areas. Nowadays the debate is finally shifting from a technology-driven vision towards a more human dimension, introducing the concepts of people friendliness and a human-to-human approach, where the user is the central focus of the whole system, and its needs and specificities are the central theme.

In this chapter, the authors will address the smart city concept as a first step towards achieving a new social-improved urban concept which may be termed the "people-friendly city". This new task involves the use of IT tools, but also the adoption of new methods and the pursuit of wider goals than that of simple numerical information. In terms of the urban environment, this means the cities should be designed for everybody, and planners need to be able to understand citizens' needs, communicate with them and involve them in a collaborative process, in order to meet their requirements through appropriate spatial planning. The people-friendly city will be based on communication and social interaction as a way of satisfying the real needs of people.

Therefore, an overview of the implications of smart cities on urban planning will be followed by an examination of Planning Support Systems (PSS) as innovative tools for enhancing the process of delivering a more inclusive and people-friendly urban environment. A rapid outline of PSS will analyse their operating framework, usability and effectiveness. The chapter will then illustrate the lessons learnt from the application of a PSS tool, in order to define the potential and key points for the development of similar tools.

BACKGROUND

From the Smart City…

In recent years the concept of smart city has become increasingly popular in the policy arena, attracting the interest both of policymakers, who are struggling to achieve the desired international ranking of smart cities in order to be more "competitive", and of private industry which is looking for places to test and develop new technologies, thus opening up a new market in the innovative services field. However, the question is: what is a smart city today, and who are its beneficiaries?

Starting from a general definition, one key aspect of the smart city concept is the use of Information and Communication Technologies (ICTs) in the process of creating more sustainable cities, as is the availability and quality of knowledge communication and social infrastructure. According to the literature, it is possible to define a set of fundamental factors which make a city 'smart': technology (hardware and software infrastructures), people (creativity, diversity and education), and institutions (governance and policy) (Papa, Gargiulo, & Galderisi, 2013). Given the interconnection of such factors, a city is smart when investments in human/social capital and IT infrastructure fuel sustainable growth and enhance the quality of life of its citizens through participatory governance (Nam & Pardo, 2009). In the last 30 years, the concept of the 'information society' has emerged (Bell, 1974; Castells, 1996; Martins, 1978), fostering the idea that new technologies and the overall information society have contributed to the birth of a new economic era in the history of mankind: this has led to a generalized belief among academics, international institutions and think tanks, that a wired, ICT-driven form would shape the future of cities, where the main focus is on the availability and quality of ICT infrastructure within the urban system.

The contemporary debate over the concept of smart cities has shifted, in recognition of the importance of the role played by human capital, social capital and relational capital through the use of ICT: the current debate has given increasing importance to users and the ways in which they utilize communication infrastructures. As Hollands (2008) pointed out, the definition of the characteristics of a smart city regards the "utilization of networked infrastructure to improve economic and political efficiency and enable social, cultural and urban development", which nowadays can also be observed in the widespread use of online social networks.

The term 'smart city' was first used in the early 1990s in order to point out how urban development was becoming increasingly dependent on technology, innovation and globalization, mainly from an economic perspective (Gibson, Kozmetsky & Smilor, 1992). However, in the last decade the term smart city has become increasingly common in the field of urban planning in particular, although "smart city" is still quite a fuzzy concept and tends to be employed in a variety of different ways: indeed, it has been used with so many different meanings that the concept seems to be in danger of becoming a new "urban label" (Hollands, 2008), and one that is often improperly used (Nam & Pardo, 2009). Since 2007, numerous scholars (Giffinger et al., 2007; Caragliu, Del Bo & Nijkamp, 2009) have tried to "bring order" to the heterogeneous definitions of the concept, and to achieve a shared vision of "smart city".

Papa et al. (2013) synthesized the main approaches as follows:

- The techno-centred approach, characterized by a strong emphasis on "hardware", that is the idea that ICT infrastructure represents the keystone for building the smart city (Cairney & Speaks, 2000; Washburn & Sindhu 2010);
- The human-centred approach, characterized by a strong emphasis on human and social capital (Partridge, 2004; Berry & Glaeser, 2005);
- The integrated approach, characterized by an emphasis both on the quality of life that a smart city should offer through the integration of technological and social innovation (Kanter & Litow, 2009), and on the capacity of cities "to create the conditions of a continuous process of learning and innovation" (Campbell, 2012).

The techno-centred approach, as mentioned earlier, was predominant in the early 2000s, and focused mainly on the technological aspects of the smart city perceived as a place capable of maximizing efficiency thanks to the widespread use of ICT. Such a vision, which has been largely sustained by multinational companies in the ICT manufacturing sector, focuses on infrastructural innovation, with citizens essentially perceived as final consumers. Nowadays, even large companies have begun to recognize that "technological devices are merely tools that can make our life better only if they are put in the hands of users who understand and can make the most of them" (Elfrink, 2012), as the vice-president of CISCO has recently declared.

The human-centred approach emerged during the second half of the 2000s, in a way counter-balancing the techno-centric vision, by proposing an alternative vision whereby social capital represents the crucial element for the creation of the smart city: ICTs, which are increasingly widely available, are considered as "enabling tools" but insufficient on their own to render an urban context "smart". Authors supporting such a vision, recognize human and social capital as a starting lever for "smart" development, as they strongly believe that a direct relationship between human capital and urban development exists. There are several voices sharing this vision, including those who emphasize the importance of a "creative class" (Florida, 2002) in terms of employees in "creative" sectors, or others highlighting the need for the close interaction of innovation, the entrepreneurial class and a highly skilled labour force (Berry & Glaeser, 2005; Glaeser & Berry, 2006).

The third, integrated approach, is today the most widely shared: it combines the two previous visions, by considering the smart city capable of using ICT to improve overall urban performances, while adopting the quality of citizens' lives as its main goal. According to this approach, what is important is the integrated, multi-sectoral vision: enhancing the performance of individual sectors (from transport to energy, construction and urban safety, etc..) through ICT does not necessarily lead to the creation of a smart city. Nowadays, the idea that a smart city represents the final goal at the end of a virtuous path, is coming to the fore: it is commonly believed that investments should be addressed to the achievement of sustainable growth, in economic and environmental terms, in order to improve citizens' quality of life and based on the involvement of settled communities (Caragliu, Del Bo, & Nijkamp, 2009).

...to the People-Friendly City

Even though the human-centred and the integrated approaches try to overcome the technocratic vision which originally gave rise to the smart city concept, we are still some way off an inclusive, people-friendly vision of the creation of cities. Critics have pointed out that this vision is based on a limited idea of what a city actually is (Graham & Crang, 2007; Greenfield, 2013; Shepard & Greenfield, 2007; de Waal, 2012), and that this smart city discourse is often entangled with neoliberal approaches to city government. In fact, rather than just a series of infrastructures to be managed as efficiently as possible, cities should also be regarded as 'communities of strangers' (Boomkens, 1998) who have to live together, and for whom a lively public sphere may be just as important. This public sphere is understood as both an opportunity for citizens to meet and develop mutual trust, as well as a place for disputing and debating the future of a city (Borja & Muxì, 2003).

The spread of ICT and new media created the opportunity to politically empower citizens as active agents of change in their own cities (Bouw, de Lange, & de Waal, 2013; Townsend, 2013). As Hemment and Townsend stated in the foreword to a recently published volume on this issue (Hemment & Townsend, 2013), "we need Smart Citizens rather than Smart Cities". This is a step forward of sorts from the human-centred approach mentioned in the previous paragraph. In this regard, two technological developments which have taken place and have became progressively popular in recent years are of particular interest. Firstly, the rise of 'big' and 'open' data combined with the opportunity to generate data through sensor networks in a bottom-up way, provides citizens with new ways to map, analyse and name salient urban issues. Secondly, the ready availability of social media platforms allows for the bottom-up mobilization and organization of the public with regard to specific issues. Together these recent developments promise to stimulate new forms of 'ownership', not in the sense of exclusive proprietorship, but as an 'inclusive form of [citizen] engagement, responsibility and stewardship.' (de Lange & de Waal, 2013)

Meanwhile, within professional circles concerned with city planning, there is an increasing interest in the involvement of citizens and other stakeholders. Approaches such as 'communicative planning', 'collaborative planning' and the use of 'crowdsourcing' recognize that, as the American Institute of Certified Planners states in its 2009 professional code, planners shall aspire to '… give people the opportunity to have a meaningful impact on the development of plans and programs that may affect them.'(Seltzer & Mahmoudi, 2013). This development is related to a broader shift in the concept of planning itself. It is currently undergoing a cultural transformation, from designing the physical urban environment as an efficient, static backdrop for inhabitation, towards the concept of "city-making". This means that planning is no longer just a decision-making process regarding the physical organization of the city. It also increasingly includes cultural aspects, liveability and social cohesion issues, and community building; whereas the process of planning is also opened up to the participation of the various stakeholders in question.

COMMUNICATION BETWEEN THE PARTIES: A QUALITATIVE APPROACH TO SPATIAL PLANNING

The city is commonly referred as a complex system (Alexander, 1965; Barabasi, 2002; Castells, 2004; Batty, 2005; Batty, 2008; Portugali, 2011; Portugali et al., 2012) which hosts different forms and functions in a complex, non-linear combination. The Complexity Theory of Cities (CTC) is based on the idea that the city is a living system which needs to be analysed using a cast number of variables, thus supporting the studies of complex urban models which have been produced since the late 1980s (Harris & Batty, 1993; Klosterman, 1994; Landis et al., 1998; Waddell, 2000; Waddell, et al., 2003; Wegener, 1994; Wegener 1995; White & Engelen, 1997; White & Engelen 2000; Wolfram, 1984). As a consequence, the need for more information, as detailed as possible, led to a great number studies of data collection, parameter calculation and the pursuit of effective indexes, and above all, to the demand for new, more powerful tools capable of employing a considerable number of variables in order to reproduce reality as a whole. Spatial models and simulations increased their input data in order on the one hand to provide more plausible forecasting solutions, and on the other hand to furnish outcomes that are capable of meeting multi-disciplinary needs. The process of the complication of spatial models has in fact reached such levels that it has become too detailed and less reliable owing to the number of variables characterised by substantial uncertainty.

Therefore, when the widespread availability of Information and Communication Technologies (ICT) is converted into the massive use thereof also within urban systems, the city becomes "smart" and replete with sensors and info panels designed to gather data regarding all types of urban behaviour.

In a sense, the smart city derives from the concept of the city as a complex system offering administrative bodies, private agencies and research institutions more reliable information that can be employed to analyse and understand how cities are used and how they work. Therefore, the smart city constitutes an ICT infrastructured city (Papa, Gargiulo, & Galderisi, 2013), which is full of, and remotely controlled by, numerous sensors providing large amounts of data – "Big Data" – offering efficient solutions for info-mobility systems, energy consumption and for health and environmental protection. Thus, Big Data represent the large amount of information that can constantly be collected, although its considerable detail requires a process of data mining capable of filtering and selecting only those data needed. Today, the drilling of Big Data is one of the most important processes underlying the development of industry, commerce and, of course, cities. The debate over this new perception of cities has led to a pragmatic approach to urban studies, with the emphasis on the deterministic conception of the use of data within the living system. Nevertheless, this strongly technology-oriented way of perceiving the growth of cities emphasises the loss of certain essential elements. First of all, it is important to think of cities as living entities which cannot be perceived as individual organisms, but as common spaces to be shared by separately acting, thinking and living individuals. Secondly, cities are part of an uncertain system which is hard to determine and control.

Thirdly, the resilience of a city to changing and developing over time is strongly dependent on its citizens' skills and on the robustness of the quality of their lives, and it becomes fully determinant when unexpected events are encountered.

The consequence of this strong tech-oriented approach is that the smart city can easily become a city of data and numbers, with people forgetting that a city is a living system populated by human beings. Moreover, these humans demand quality lives, and have little interest in the quantities that measure such lives. Therefore, while a smart city should gather data and formulate indexes for measuring the Quality of Life (QoL), it should also use this information to implement a network of individuals, and to increase the opportunities for knowledge building, that is, it has to support social inclusion and communication between the parties involved.

The widespread use of technology demands a new humanism in which Man regains his position as the focal point of collective reasoning. Therefore, the smart city should propose an infrastructure capable of supporting data use by end-users, be they professionals or citizens, while providing free accessibility to information. Nevertheless, in order to achieve knowledge and, in particular, awareness of the living environment, end-users need to be led to manage this huge amount of information. Thus, "smart policy makers" should work on the education and social inclusion of people in order to enable them to filter data, explore information and develop their own knowledge.

Efforts are being made to create tools that monitor the qualitative aspects of our lives, collecting data and information on our perception of wellness and well-being: this shift witnesses increasing importance being given to "subjective" aspects, that is to say, that there is no right or wrong way of creating a city according to best practices, but there are solutions to be adopted that reflect residents' needs and expectations. Listening to them and involving them in the decision-making process is the first step towards a more people-friendly urban environment.

PLANNING SUPPORT SYSTEMS: AN OVERVIEW OF THE STATE OF ART

In the last two centuries, urban planning has become increasingly multifaceted. The growth of industrial activity, the consequent densification of the population and the evolution of the middle classes, has changed the form and functions of cities, so that urban planning has had to deal with new issues such as supplying energy to factories, dense residential areas and environmental pollution. Likewise, the widespread use of private cars required cities to find solutions for the consequent new requirements, such as wider roads and parking places. Therefore, urban functions have substantially changed and have profoundly impacted the form of cities, requiring new planning paradigms. Several theoretical studies prevalent during the 1960s, led to the development of a variety of different urban models. However, a set of bottlenecks were identified which made such unsuitable for dealing with this new urban complexity (Lee, 1973).

A refreshing new tone was set in the late '80s, thanks to the rapid development of graphic interfaces and micro-simulation systems. A variety of new instruments had emerged, ranging from electronic conference board rooms (group decision support systems) (Laurini, 1998), GIS-supported collaborative decision-making tools (Nyerges & Jankowski, 1997), Web-based mediation systems for co-operative spatial planning (Gordon et al., 1997; Shiffer, 1992), and support tools for different planning tasks (Geertman, 2002; Hopkins, 1999; Kammeier, 1999; Klosterman, 1999; Singh, 1999). Commonly defined as Planning Support Systems (PSS), these tools have been largely developed in order to establish new approaches to urban planning processes.

Nevertheless, their limited application to real situations has pointed to certain limitations to their usability. In general, as Brömmelstroet (2010) has pointed out, the various PSS are seen by their intended users as "inadequate, far too generic, complex, too technology oriented (rather than problem oriented), not transparent enough, neither flexible nor user friendly, too narrowly focused on strict technical rationality, and incompatible with the unpredictable/flexible nature of most planning tasks and information needs (Bishop, 1998; Couclelis, 1989; Geertman & Stillwell, 2003; Harris & Batty, 1993; Lee, 1973; Lee 1994; Sieber, 2000; Uran & Janssen, 2003; Batty, 2003; Vonk, 2006). This list of limitations highlights the fact that increasing computational capabilities cannot solve the majority of the aforementioned bottlenecks, which mainly involve social and communicative issues.

In order to promote the real use of PSS in planning practice, a more inclusive, people-friendly approach is needed. Improved structured communication between potential users and PSS developers should be adopted. End users should be consulted at all stages of the development process, through the adoption of approaches such as the Living Lab (European Commission, 2009; de Waal & Melis, 2015), a technique mainly used in the business sector to facilitate the engagement of stakeholders and their understanding of planning problems, as well as the setting of criteria for PSS, thus permitting a transparent process. Only by creating strong methods of communication between the human parties to the planning processes, can the smart city be converted into a people-friendly city. Therefore, PSS should be capable of encouraging users to make their own choices by providing a transparent platform to be used to share information with one another. Thus, PSSs should not focus on measuring indexes, but on methods for getting people to understand the indexes and to discuss planning issues.

THE DEVELOPMENT OF THE INTERACTIVE VISUALISATION TOOL (InViTo): A METHOD FOR COMMUNICATING DATA TO NON-EXPERTS

In view of the previous observations regarding the actual usability of PSS, a new tool has been proposed based on communication and discussion among stakeholders on the one hand, and the availability of open technology and data on the other, and this new tool has been utilised in different case studies in Europe as an initial step towards the establishment of more people-friendly smart cities.

If the smart city is to be seen as an ICT infrastructured metropolitan area, then policy makers need to offer "smart" citizens the opportunity to use and interact with this digital infrastructure in order to obtain the information they require. However, communications and information-sharing among people remains a difficult objective. The will to involve citizens, and to guarantee their inclusion in collective processes, are problems that need to be overcome in urban practices. However, while the latter depends on the former, both are consequences of a limited cultural grounding in the participation of citizens in the "*res publica*".

Therefore, permitting the participation of citizens and professionals in the decision-making processes underlying the future development of a city, is of essential importance if we are to have smart citizens. For example, a large number of people and considerable expertise are commonly involved in spatial planning and decision-making processes, and thus communication among people is indispensable in order to increase the likelihood of successful, effective growth. Nevertheless, tools conceived to support those processes often aim at converting the qualitative exchange of opinions into a quantitative automatic process, thus bringing the debate around to the question of numbers rather than human needs. Moreover, the usability of Decision Support Systems (DSS) is often threatened by a knowledge gap separating tool developers, urban planning practitioners and other possible users such as citizens participating in the process.

In order to overcome such an approach, researchers are looking for innovative methods capable of enhancing the social factors within urban planning processes. Therefore, the smart city concept can be more generally developed by focusing on the use and usability of the tools used to create cities, by focusing more on the construction of multiple networks among people, and by promoting a new vision which establishes the people-friendly city as a new frontier for the enhancement of social inclusion within metropolitan areas.

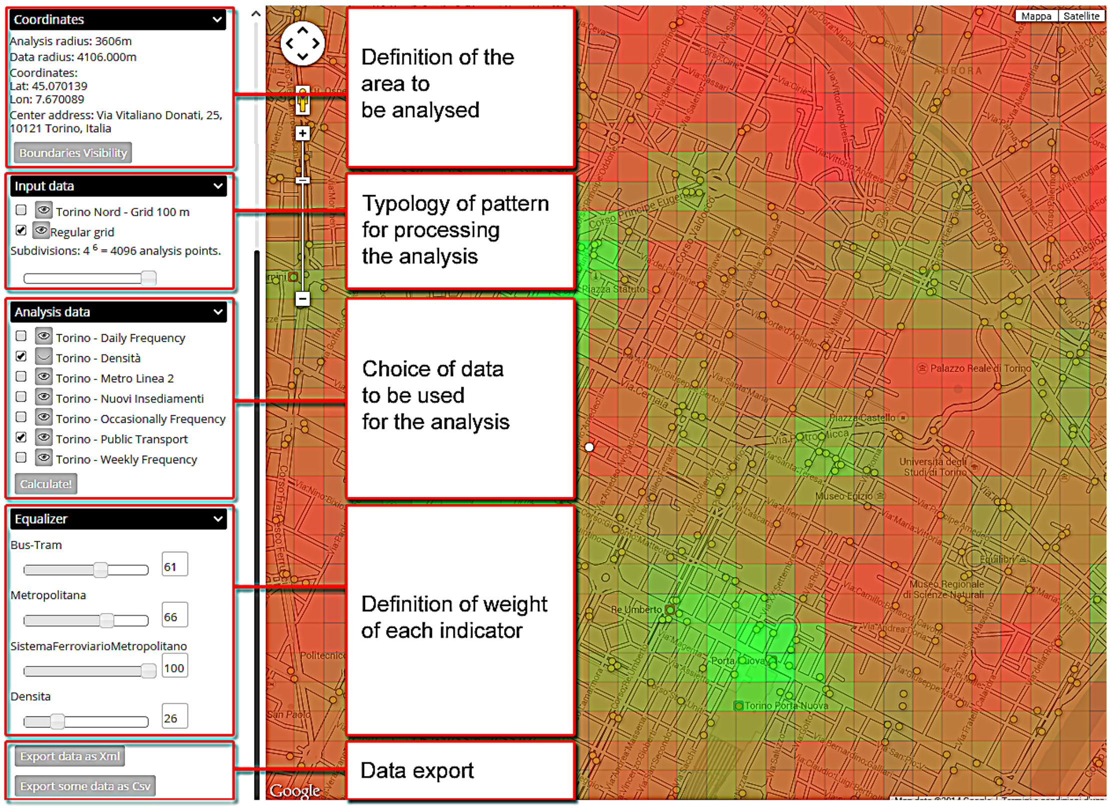
Among such recent attempts, the Interactive Visualization Tool (InViTo) tries to combine automatic processing with a human approach to spatial planning, by means of real-time visual communications.

InViTo is a planning support tool based on the idea that communication among people is the first factor in increasing the likelihood of the successful outcome of spatial planning and projects. It has enhanced the debate since its initial implementation, by stimulating dialogue through a form of visual representation that interactively changes as a result of end-users' choices (Pensa & Masala, 2014). Users are invited to discuss the selection and relative importance of the indicators to be included in the analysis, the parameters to be considered and their respective weight: InViTo enhances cooperation from the earliest stages of such. The opportunities offered by the tool are taken full advantage of when the actors involved in the process and sitting at the discussion table, actually represent the entire spectrum of stakeholders within an urban area: InViTo allows non-experts to participate in the discussion, as it collects ratings based on people's perceptions of the problem, by posing simple questions and cross-referencing them. This method is taken from the multiple-criteria decision analysis (MCDA) approach, and is based on the expression of preferences from among alternatives. Data collected in such a way are then merged in order to get the general feeling of the users: this first phase can be carried out through a survey with questionnaires, or involve face-to-face meetings, depending on the number of participants.

Results are then visualized on a simple chromatic scale, and the output is represented by a map summarizing complexity, i.e. the behaviour of each indicator: being an interactive tool, InViTo enables changes to be shown in real time, together with multiple scenarios, in order to compare the expected impact of different approaches and choices.

Nowadays, InViTo is evolving towards a web version which organises data in a framework where information are gathered and explored through a simple interface consisting of a map and a number of menus (see Figure 1). This feature makes the tool freely accessible to both professionals and citizens, who can easily and quickly examine data thanks to the organised structure. InViTo does not require any particular training to be used, as its interface is designed to be immediately understood. Consequently, end-users are facilitated

Figure 1. User interface of the web version of InViTo



in interacting with information and in building their own awareness and knowledge of specific issues, by analysing a spatial problem through the intersection of different layers.

In fact, the tool is designed to support multi-criteria analysis, with the peculiarity of its map-based visualisation designed to localise the data shown.

In particular, the information framework generated by the use of InViTo shows decision-makers what they cannot see, thus enabling them to explore the hidden connections behind what is commonly referred to as a complex system. The filtering, selection and intersection of data by the user, highlights specific relationships between identified groups of data, thus creating information clusters or outlining critical behaviours.

Thanks to this feature, the positive and negative effects on a territory can be overlaid on a map and analysed by non-expert users as well, who can intuitively see how an area may be affected by specific events or by specific choices. Given that InViTo is a customizable, adaptable tool, it can be used for a variety of different purposes such as the planning of new infrastructures, services and facilities, deciding where is it more desirable to live according to individuals' specific needs, and evaluating the accessibility of an area, to mention just a few.

InViTo is a very flexible tool that can be customized to fit the planning problem. Until now, it has been tested in different contexts and scales, such as brownfield redevelopment (Masala & Melis, 2014), or transport strategy assessment at the interregional level (Pensa, et al., 2014), as well as morphological planning in urban areas (Pensa, Masala, & Marina, 2013). It makes use of various types of data, including open data, data from social networks and GIS data, in order to generate visual representations of information which can provide an intuitive framework for knowledge building.

Furthermore, the use of InViTo allows data collected within a smart city to be used for the planning of the city itself, providing a trans-disciplinary, comprehensive vision of the complex reality.

Finally, its real time output elaboration genuinely encourages dialogue between people, comments about choices to be taken, and scenario comparisons. Therefore, the tool facilitates a vision of the future impacts of urban planning decisions, thus providing a shared input for subsequent discussion and decision-making.

FUTURE RESEARCH DIRECTIONS

Since the early '90s, with the advent of the Internet and the World Wide Web, the city has acquired a new technological infrastructure that has resulted in a real revolution characterized by the substantial modification not only of the nature of society, but also of the way physical space is planned and managed. During this period, a virtual society of people using this infrastructure has begun to produce a virtual world, consisting of data and information from the real world, that are used to simulate its complexity. In this context, the virtual world and the real world are closely interconnected and interdependent, and the use of data is fundamental to understanding the relationship between the environment and human behaviour.

However, the very fact that there has been a greater focus on technologies than on people helps explain the lack of success of a number of applications over the past two decades: for example, decisional support tools have been developed mainly for the purposes of academic research, rather than to support urban planning practices (te Brömmelstroet et al., 2014).

Current technologies and tools already offer useful ways of supporting those planning processes aimed at facilitating communication between developers and practitioners, together with the interaction of all the stakeholders involved: more effective solutions can be represented by adopting a more cooperative, bottom-up approach that places greater emphasis on the social and environmental aspects.

In recent years, cities have become increasingly complex, and their citizens have shown great interest in participating and being involved in different areas of public decision-making, and thus participatory processes have become extremely important. This is the direction in which certain innovative projects are going when addressing the planning process by focusing more on technological tools than on social issues.

Although the use of tools based on the quantitative approach to describe and analyse urban and social phenomena dates back to several decades ago, it is nowadays becoming increasingly important following the ever greater complexity of our cities and their on-going transformation processes. In this context, Information and Communication Technology (ICT) has taken great strides forward in terms of both the visualization and the simulation of urban contexts, thus facilitating dialogue among experts from different sectors (urban and regional planning, geography, sociology, transport planning, urban economics and so on).

Nevertheless, the difficulty of expressing complex issues by means of models and quantitative data, represents a possible limitation to the effectiveness of the tools in question: hence such tools should be used with extreme caution. However, many different experiences have demonstrated the usefulness of technology within the context of participatory processes, if only for the fact this calls for a structured approach to complex issues.

While the use of tools and data represents an important aid in planning processes, it is very important not to forget that cities are primarily made up of people.

The oft-abused concept of "smart city" sometimes causes confusion, as it suggests that technologies are the key factor for the future of our cities, whereas in reality they should represent enablers for people. Hence the fundamental, central role of citizens, who are at one and the same time the creators and the users of cities, and thus technology must focus on, and be designed for, the citizens.

Given the importance of the involvement of citizens, and the increasing complexity of our cities, it is important that technologies become increasingly capable of communicating in a simple, intuitive way, for example through real-time interaction and three-dimensional visualization, so to help decision makers, practitioners and simple citizens to get their bearings in an environment characterized by multiple variables.

For this reason, it is very important to provide technologies which are as user friendly as possible, in order to facilitate the interaction of both practitioners and simple citizens, and to guide them towards a vision of the city which is not only smart, but also, and in particular, liveable.

This perspective permits effective interaction through the use of tools to simulate as far as possible the urban dynamics that arise, for example, from design assumptions.

As far as concerns the decision support tool "InViTo" presented above, an analysis of past experiences and the experimental use of the tool have made it possible to offer a number of considerations designed to avoid a repetition of past mistakes, in order to address social, economic and environmental sustainability through the development of Smart Cities. In this regard, a number of important factors must be taken into consideration, in order to move from the concept of smart cities to that of people-friendly cities, involving the development of mobile technologies, the use of big data for interpreting human behaviour, and the increased involvement of citizens through the adoption of innovative methods of involving citizens, such as crowd-mapping, crowd-sourcing, etc… not to mention the possibility of collecting data from social networks in order to explore urban dynamics.

Switching to another way of gathering information, in order to provide citizens with the instruments they need to support planning, as well as present and future research, can be based on monitoring and sensor systems, bearing in mind that this question, previously trialled in South Korea through the "Ubiquitous City" Project (U-City), requires the greater involvement of citizens and must focus on real problems rather than on technologies.

U-City is a 21st century futurist city characterized by services such as a one-stop administration service, automatic traffic, a crime prevention system and the home-networking of residential places merging high-tech infrastructure and a ubiquitous information service within the urban area (Jang & Shu, 2010).

What emerges from initial experiments is that a smart city should pay equal attention to data gathering and data restitution: citizens are not only "human sensors" and data producers serving the city by offering knowledge for the purposes of more informed decision-making processes, but they are above all the residents and users of the city, the first and most important actors in the process. Therefore, they have to be involved and informed about how their own society and living environment is working: this is possible nowadays thanks on the one hand to open data and technologies, and on the other hand to the much-pursued transparency and accountability of governance structures.

In view of the previous considerations, we can state that the most interesting characteristics of InViTo, seen as a means towards a more inclusive decision-making process, is its flexibility and adaptability to different situations, as well as its potential real-time interaction. Such characteristics represent an excellent starting point for the application of such a tool to several areas ranging from participatory processes to public debate, as it supports planning processes through its attempt to represent the complex behaviour underlying the dynamics of the city.

InViTo, just like many other tools that are currently being developed throughout the world, is being gradually improved in order to rectify those omissions and weaknesses that emerged during testing. While on the one hand, the usability of InViTo (compared to its initial version) has improved with the creation of a web-based version (InViTo 2.0), on the other hand certain limitations still need to be rectified in order to make the tool truly effective: the 3D visualization option designed to make it more user-friendly and immediately graspable by non-expert users, and the calculation of distances on the basis of the road network, designed to bridge the gap between the model and reality, represent just two of the numerous new features that are currently being developed.

CONCLUSION

This chapter attempts to show that current technologies and tools can already offer new ways of supporting planning processes. However, it is also based on the assumption that cities have to guarantee their citizens liveable spaces, rather than simply providing them with technology. It is necessary to decide where the main focus lies within the concept of smart cities: technologies or people?

The involvement of leading ICT companies (IBM, Cisco, Eriksson, etc.) in smart city projects demonstrates their interest in promoting the use of data and technology. However, the risk in basing considerations regarding smart cities mainly on technologies is to lose sight of those aspects which are immeasurable, such as sensations, perceptions, etc., in other words, humanity.

Technologies are not people-friendly *per se*, but become so when they are user friendly and are actually used in order to promote certain behaviour that makes our cities more liveable and sustainable (i.e. increased use of bicycles, public transport, pedestrian areas, etc…) thus promoting a better quality of life.

From this point of view, technologies are not the final goal, but represent the enabler facilitating people's life: they are the mean of rendering cities people-friendly, but if their use is excessively complicated, their effect will be limited or may generate disparities (inequalities). Technologies represent the means, and not the ends, and as such they must be integrated with other elements offered by our cities, first and foremost an attention to inclusiveness and equality. The instrument presented in this chapter, InViTo, represents a good example of this for several reasons. First of all it is not based on data collection, but on human perceptions. Furthermore, it aims to provide information that will encourage the debate among the various different stakeholders. Finally, it is designed to increase people's participation.

The application of InViTo to real planning situations has drawn attention to the need for further effort to be made towards moving away from a quantitative approach to technology, towards a new qualitative method capable of enhancing human perception. A tool like InViTo facilitates the comprehension of planning problems, allowing the participation of non-expert citizens as well as technicians and decision makers.

In fact, the effectiveness of the tool lies in its ability to guide people towards an understanding of the changes affecting their cities, and to help them express their opinions. Its application shows that a further shift can be made from the concept of the "smart city" which primarily collects data, to the "people-friendly city" which uses such data to implement planning processes, and consequently to improve the quality of its citizens' lives.

Technology represents an essential element for those cities wishing to compete on a global scale. However, it has been claimed that the huge expectations of smart cities based mainly on technology, are not actually met. Hence the need for a re-think of the issue, and for its redirection away from a design-based paradigm towards a human-based one.

REFERENCES

Alexander, C. (1965). A city is not a tree. *The Architectural Forum*, *122*(1), 58–62.

Barabasi, A. L. (2002). *Linked. The New Science of Networks*. Cambridge, MA: Perseus Publishing.

Batty, M. (2003). Planning support systems: technologies that are driving planning. In S. Geertman & J. Stillwell (Eds.), *Planning Support Systems in Practice*.

Batty, M. (2005). *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based*. Cambridge, MA: The MIT Press.

Batty, M. (2008). *Cities as Complex Systems: Scaling, Interactions, Networks, Dynamics and Urban Morphologies*. CASA working papers series 131.

Bell, D. (1974). *The coming of post-industrial society*. London: Heinemann.

Berry, C. R., & Glaeser, E. L. (2005). The divergence of human capital levels across cities. *Papers in Regional Science*, *84*(3), 407–444. doi:10.1111/j.1435-5957.2005.00047.x

Biderman, A. (2013). *Living in an Open-Air Computer*. Retrieved February 13, 2014, from http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2013/_html_en/interview-city-lab.html

Bishop, I. (1998). Planning Support: Hardware and software in search of a system. *Computers, Environment and Urban Systems*, *22*(3), 189–202. doi:10.1016/S0198-9715(98)00047-7

Boomkens, R. (1998). *Een drempelwereld: Moderne ervaring en stedelijke open-baarheid*. Rotterdam: NAI Publisher.

Borja, J., & Muxi, Z. (2003). *El espacio público: ciudad y ciudadanía*. Barcelona: Electa.

Bouw, M., de Lange, M. d., & de Waal, M. d. (2013). De hackable wereldstad. In j. Lekkerkerker, & S.d. Vries (Eds.), Ruimtevolk jaarboek 2013. nieuw kapitaal (pp. 163-167). Ruimtevolk.

Cairney, T., & Speak, G. (2000). *Developing a "smart city": Understanding Information Technology Capacity and Establishing an Agenda for Change*. Retrieved November 30, 2014, from http://trevorcairney.com/wp-content/uploads/2012/11/IT_Audit.pdf

Campbell, T. (2012). *Beyond Smart Cities: How cities network, learn and innovate*. New York, NY: Routledge.

Caragliu, A., Del Bo, C., & Nijkamp, P. (2009). Smart cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. doi:10.1080/10630732.2011.601117

Castells, M. (1996). The Information Age: Economy, Society and Culture.: Vol. I. *The Rise of the Network Society*. Malden, MA; Oxford, UK: Blackwell.

Castells, M. (2004). *La Città delle Reti* [The Network Society]. Venice, Italy: Marsilio.

Couclelis, H. (1989). Geographically informed planning: requirements for planning relevant GIS. In *Proceedings of 36th North American Meeting of Regional Science Association*. Santa Barbara.

de Lange, M., & de Waal, M. (2013). Owning the city: New media and citizen engagement in urban design. *First Monday*, *18*(11). doi:10.5210/fm.v18i11.4954 de Waal, M. (2012). The ideas and ideals in urban media. In M. Foth (Ed.), *From social butterfly to engaged citizen*. Cambridge, MA: MIT Press.

de Waal, M., & Melis, G. (2015). Urban Living Labs & City-making: Open innovation and urban design. In E. Almirall & B. Cohen (Eds.), *Open Innovation as a driver for Smart Cities*. Netherlands: Springer.

Elfkrink, W. (2012). Foreword. In Campbell, T. *Beyond Smart City: How cities network, learn and innovate.* New York, NY: Routledge.

European Commission. (2009). *Living Labs for user-driven open innovation: An overview of the Living Labs methodology, activities and achievements*. Retrieved November, 30, 2014, from http://www.eurosportello.eu/sites/default/files/Living%20Lab%20brochure_jan09_en_0.pdf

Florida, R. (2002). The economic geography of talent. *Annals of the Association of American Geographers*, *92*(4), 743–755. doi:10.1111/1467-8306.00314

Geertman, S. (2002). Participatory planning and GIS: A PSS to bridge the gap. *Environment and Planning. B, Planning & Design*, *29*(1), 21–35. doi:10.1068/b2760

Geertman, S., & Stillwell, J. (Eds.). (2003). *Planning Support Systems in Practice*. Berlin, Germany: Springer. doi:10.1007/978-3-540-24795-1

Gibson, D. V., Kozmetsky, G., & Smilor, R. W. (Eds.). (1992). *The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Networks*. New York, NY: Rowman & Littlefield.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., & Meijers, E. (2007). *Smart cities. Ranking of European medium-sized cities*. Retrieved November, 30, 2014, from http://www.smartcities.eu/download/smart_cities_final_report.pdf

Glaeser, E. L., & Berry, C. R. (2006). *Why are smart places getting smarter?* Cambridge, MA: Taubman Centre.

Gordon, T., Karacapilidis, N., Voss, H., & Zauke, A. (1997). Computer-mediated cooperative spatial planning. In H. Timmermans (Ed.), *Decision support systems in urban planning* (pp. 299–309). E & FN Spon.

Graham, S., & Crang, M. (2007). Sentient cities: Ambient intelligence and the politics of urban space. *Information Communication and Society*, *10*(6), 789–817. doi:10.1080/13691180701750991

Greenfield, A. (2013). *Against the smart city*. New York: Do projects.

Harris, B., & Batty, M. (1993). Locational models, geographical information and planning support systems. *Journal of Planning Education and Research*, *12*(3), 84–98. doi:10.1177/0739456X9301200302

Hemment, D., & Townsend, A. (2013). *Smart citizens*. Retrieved November 30, 2014, from http://futureeverything.org/wp-content/uploads/2014/03/smartcitizens1.pdf

Holland, R. G. (2008). Will the Real Smart City Please Stand Up? *City*, *12*(3), 303–320. doi:10.1080/13604810802479126

Hopkins, L. (1999). Structure of a planning support system for urban development. *Environment and Planning. B, Planning & Design*, *26*(3), 333–343. doi:10.1068/b260333

Jang, M., & Shu, S. (2010). *U-City: New trends of Urban Planning in Area based on Pervasive and Ubiquitous Geotechnology and Geoinformation*. Berlin: Springer.

Kammeier, H. (1999). New tools for spatial analysis and planning as components of an incremental planning-support system. *Environment and Planning. B, Planning & Design*, *26*(3), 365–380. doi:10.1068/b260365

Kanter, R. M., & Litow, S. S. (2009). *Informed and Interconnected: A Manifesto for Smarter Cities*. Retrieved November 30, 2014 from http://www.hbs.edu/faculty/Publication%20Files/09-141.pdf

Klosterman, R. (1999). The What if? collaborative planning support system. *Environment and Planning. B, Planning & Design*, *26*(3), 393–408. doi:10.1068/b260393

Klosterman, R. E. (1994). Large-Scale urban models - Retrospect and prospect. *Journal of the American Planning Association*, *60*(1), 3–6. doi:10.1080/01944369408975545

Landis, J. D., Monzon, J. P., Reilly, M., & Cogan, C. (1998). *The California Urban and Biodiversity Analysis Model: Theory and Pilot Implementation*. Berkeley: UC Berkeley, Institute of Urban and Regional Development.

Laurini, R. (1998). Groupware for urban planning: An introduction. *Computers, Environment and Urban Systems*, *22*(4), 317–333. doi:10.1016/S0198-9715(98)00029-5

Lee, D. B. Jr. (1973). Requiem for Large-Scale Models. *Journal of the American Institute of Planners*, *39*(3), 163–177. doi:10.1080/01944367308977851

Lee, D. B. (1994). Retrospective on large-scale urban models. *Journal of the American Planning Association*, *60*(1), 35–40. doi:10.1080/01944369408975549

Martins, J. (1978). *The Wired Society*. New Jersey: Prentice-Hall.

Masala, E., & Melis, G. (Eds.). (2014). *Interactive Visualisation tool for brownfield redevelopment - A European experience*. Torino, Italia: Celid.

Nam, T., & Pardo, T. A. (2009). Conceptualizing Smart City with Dimensions of Technology, People, and Institutions. In *Proceedings of Annual International Conference on Digital Government Research*.

Nyerges, T., & Jankowski, P. (1997). Adaptive structuration theory: A theory of GIS-supported collaborative decision making. *Geographical Systems*, *4*(3), 225–259.

Papa, R., Gargiulo, C., & Galderisi, A. (2013). Towards an urban planners' perspective on smart city. *TeMA - Journal of Land Use*. *Mobility and Environment*, *6*(1), 5–17.

Partridge, H. (2004). *Developing a human perspective to the digital divide in the Smart City*. Retrieved from http://eprints.qut.edu.au/1299/1/partridge.h.2.paper.pdf

Pensa, S., & Masala, E. (2014). InViTo: An Interactive Visualisation Tool to Support Spatial Decision Processes. In N. N. Pinto, J. A. Tenedorio, A. P. Antunes, & J. R. Cladera (Eds.), *Technologies for Urban and Spatial Planning: Virtual Cities and Territories* (pp. 135–153). Hershey, PA: IGI Global Book.

Pensa, S., Masala, E., Lami, I. M., & Rosa, A. (2014). Seeing is knowing: data exploration as a support to planning. *Proceedings of the ICE - Civil Engineering, 167*(5), 3-8.

Pensa, S., Masala, E., & Marina, O. (2013). What if form follows function? The exploration of suitability in the city of Skopje. *Disegnare Con*, *6*(11), 141–148.

Portugali, J. (2011). *Complexity Cognition and the City*. Berlin: Springer Heidelberg. doi:10.1007/978-3-642-19451-1

Portugali, J., Meyer, H., Stolk, E., & Tan, E. (Eds.). (2012). *Complexity Theories of Cities Have Come of Age*. Berlin, Heidelberg: Springer. doi:10.1007/978-3-642-24544-2

Seltzer, E., & Mahmoudi, D. (2013). Citizen participation, open innovation, and crowdsourcing challenges and opportunities for planning. *Journal of Planning Literature*, *28*(1), 3–18. doi:10.1177/0885412212469112

Shepard, M., & Greenfield, A. (2007). *Situated technologies pamphlet 1: Urban computing and its discontents*. New York: The Architectural League of New York.

Shiffer, M. (1992). Towards a collaborative planning system. *Environment and Planning. B, Planning & Design*, *19*(6), 709–722. doi:10.1068/b190709

Sieber, R. (2000). GIS implementation in the grassroots. *URISA Journal*, *12*, 15–29.

Singh, R. (1999). Sketching the city: A GIS-based approach. *Environment and Planning. B, Planning & Design*, *26*(3), 455–468. doi:10.1068/b260455

te Brömmelstroet, M. C. (2010). Equip the warrior instead of manning the equipment: Land use and transport planning support in the Netherlands. *Journal of Transport and Land Use*, *3*, 25–41.

te Brömmelstroet, M. C., Silva, C., & Bertolini, L. (2014). *COST Action TU1002 - Assessing Usability of Accessibility Instruments.* Retrieved November 30, 2014, from http://www.accessibilityplanning.eu/wp-content/uploads/2014/05/COST-REPORT-II.pdf

Townsend, A. M. (2013). *Smart cities: Big data, civic hackers, and the quest for a new utopia*. WW Norton & Company.

Uran, O., & Janssen, R. (2003). Why are spatial decision support systems not used? Some experiences from the Netherlands. *Computers, Environment and Urban Systems*, *27*(5), 511–526. doi:10.1016/S0198-9715(02)00064-9

Vonk, G. (2006). *Improving planning support; the use of planning support systems for spatial planning*. Utrecht: Nederlandse Geografische Studies.

Waddell, P. (2000). A behavioral simulation model for metropolitan policy analysis and planning: Residential location and housing market components of UrbanSim. *Environment and Planning. B, Planning & Design*, *27*(2), 247–263. doi:10.1068/b2627

Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M., & Ulfarsson, G. (2003). *Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim*. Netherlands: Springer.

Washburn, D., & Sindhu, U. (2010). *Helping CIOs Understand "Smart City" Initiatives*. Retrieved from http://www.uwforum.org/upload/board/forrester_help_cios_smart_ city.pdf

Wegener, M. (1994). Operational Urban Models State of the Art. *Journal of the American Planning Association*, *60*(1), 17–29. doi:10.1080/01944369408975547

Wegener, M. (1995). Current and Future Land Use Models. In *Proceedings of Land Use Model Conference*. Texas.

White, R., & Engelen, G. (1997). Cellular automata as the basis of integrated dynamic regional modelling. *Environment and Planning. B, Planning & Design*, *24*(2), 235–246. doi:10.1068/b240235

White, R., & Engelen, G. (2000). High-resolution integrated modelling of the spatial dynamics of urban and regional systems. *Computers, Environment and Urban Systems*, *24*(5), 383–400. doi:10.1016/S0198-9715(00)00012-0

Wolfram, S. (1984). Cellular automata as model of complexity. *Nature*, *311*(5985), 419–424. doi:10.1038/311419a0

ADDITIONAL READING

Abbott, E. A. (1884). *Flatland: A Romance of Many Dimensions*. UK: Seely & Co.

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M. J., MacEachren, A. M., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, *21*(8), 839–857. doi:10.1080/13658810701349011

Andrienko, G., Andrienko, N., Keim, D., MacEachren, A., & Wrobel, S. (2011). Challenging problems of geospatial visual analytics. *Journal of Visual Languages and Computing*, *22*(4), 251–256. doi:10.1016/j.jvlc.2011.04.001

Batty, M. (2000). *Visualizing the city: urban design to planners and decision makers*. CASA working papers series 26.

Bertin, J. (1967). *Semiologie Graphique: les Diagrammes, les Reseaux, les Cartes*. Paris, France: Mouton and Co.

Borges, J. L. (1960). *El hacedor*. Buenos Aires, Argentina: Emecé.

Calvino, I. (1972). *Le Città Invisibili*. Turin, Italy: Einaudi.

Card, S. K., Mckinlay, J. D., & Shneiderman, B. (1999). *Readings in Information Visualization: Using Vision to Think*. Burlington, MA: Morgan Kaufmann.

COST. (n.d.). *Accessibility instruments for planning practice in Europe*. Retrieved September 25, 2012, from http://www.accessibilityplanning.eu/

Couclelis, H. (2003). Where has the future gone? Rethinking the role of integrated land use models in spatial planning. In *Proceedings of Framing Land Use Dynamics: Reviewed Abstracts International Conference* (pp. 27-28). Utrecht.

De Rossi, A., & Durbiano, G. (2006). *Torino 1980-2011, La trasformazione e le sue immagini*. Turin, Italy: Umberto Allemandi.

Dematteis, G. (1985). *Le Metafore della Terra: la Geografia Umana tra Mito e Scienza*. Milan, Italy: Feltrinelli.

ESRI. (2012). *ESRI CityEngine - Smart 3D city models.* Retrieved December 5, 2012, from http://www.esri.com/software/cityengine

Farinelli, F. (2007). *L'invenzione della Terra*. Palermo, Italy: Sellerio.

Fuhrmann, S., & Ahonen-Rainio, P. (2005). Making useful and usable geovisualization: design and evaluation issues. In J. A. Dykes, A. M. MacEachren, & J. Kraak (Eds.), *Exploring Geovisualization*. Oxford, UK: Elsevier Ltd. doi:10.1016/B978-008044531-1/50446-2

Geertman, S. C., & Stillwell, J. (2009). *Planning Support Systems: New Methods and Best Practice (Advances in Spatial Science)*. New York, NY: Springer Publishers. doi:10.1007/978-1-4020-8952-7

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal*, *69*(4), 211–221. doi:10.1007/s10708-007-9111-y

Heer, J., & Agrawala, M. (2008). Design considerations for collaborative visual analytics. *Information Visualization*, *7*(1), 49–62. doi:10.1057/palgrave.ivs.9500167

International Cartographic Association. (2011). *Directory 2011-2015*. Retrieved November 30, 2014, from http://icaci.org/files/documents/reference_docs/2011-2015_directory.pdf

Klosterman, R. E. (2012). Simple and complex models. *Environment and Planning. B, Planning & Design*, *39*(1), 1–6. doi:10.1068/b38155

Klosterman, R. E., & Pettit, C. (2005). Editorial: An update on planning support systems. *Environment and Planning. B, Planning & Design*, *32*(4), 477–484. doi:10.1068/b3204ed

Latour, B. (1987). *Science in action. How to follow scientists and engineers through society*. Harvard, MA: Harvard University Press.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press.

Masala, E. (2014). Visualisation as a support to spatial decision processes: some considerations on the concepts behind the construction of a strategy image. In E. Masala & G. Melis (Eds.), *Interactive Visualization Tool for brownfield redevelopment - A European experience* (pp. 81–94). Torino: Celid.

MIT - Senseable City Lab. (2008). *CurrentCity*. Retrieved May 24, 2012, from http://senseable.mit.edu/currentcity/

MIT - Senseable City Lab. (2009). *The Copenhagen Wheel- Data Visualization*. Retrieved April 28, 2011, from http://www.youtube.com/watch?v=U5k25-hHNrc

MIT - Senseable City Lab. (2012). *Spring Spree – spending patterns in Spain during Easter 2011*. Retrieved May 25, 2012, from http://senseable.mit.edu/bbva/

Simao, A. (2009). Web-based GIS for collaborative planning and public participation: An application to the strategic planning of wind farm sites. *Journal of Environmental Management*, *90*, 2027–2040. doi:10.1016/j.jenvman.2007.08.032 PMID:18621467

Snyder, K. (2001). Tools for community design and decision-making. In S. Geertman & J. Stillwell (Eds.), *Planning Support Systems in Practice* (pp. 99–120). Heidelberg, Germany: Springer.

Spence, R. (2007). *Information Visualization: Design for Interaction*. Upper Saddle River, NJ: Prentice Hall.

Stasko, J. (2008). Visualization for Information Exploration and Analysis. In *Proceedings of ACM symposium on Software visualization* (pp. 7-8). doi:10.1145/1409720.1409721

te Brömmelstroet, M. C. (2009). The relevance of research in planning support systems: A response to Janssen et al. *Environment and Planning. B, Planning & Design*, *36*(1), 4–7. doi:10.1068/b3601com

Tufte, E. R. (1990). *Envisioning Information*. Cheshire, CT: Graphics Press.

Vonk, G., Geertman, S., & Schot, P. (2005). Bottlenecks blocking widespread usage of planning support systems. *Environment & Planning A*, *37*(5), 909–924. doi:10.1068/a3712

KEY TERMS AND DEFINITIONS

City: A complex, intricate system which should facilitate interaction and communication among people.

Communication: A method of achieving smart citizens.

Knowledge Building: The only goal technicians and experts should have when producing their outcomes, a goal which lies at the basis of social inclusion, of awareness when taking decisions, and of the protection of our environment.

Participation: Playing an active role in shaping one's own urban environment.

People-Friendly: Made for everybody's needs and capabilities.

Quality of Life: The only goal decision-makers should have when building cities.

Support System: A system which can enable or enhance human skills in both individual and collective work.

Sustainability: An over-used term which indicates the ability of our environment to provide the resources we are using also for the future generations.

Visualisation: A discipline which permits intuitiveness in regard to communication among people and to the gathering of information in the human-machine exchange.

Chapter 18
Mobility, Data, and Behavior:
The TrafficO_2 Case Study

Salvatore Di Dio
Scuola Politecnica Università degli Studi di Palermo, Italy

Fabrizio Micari
Scuola Politecnica Università degli Studi di Palermo, Italy

Barbara Lo Casto
Scuola Politecnica Università degli Studi di Palermo, Italy

Gianfranco Rizzo
Scuola Politecnica Università degli Studi di Palermo, Italy

Ignazio Vinci
Scuola Politecnica Università degli Studi di Palermo, Italy

ABSTRACT

This chapter presents the social innovation project "TrafficO_2", a support system for decision-making in the field of transportation that tries to push commuters towards more sustainable mobility by providing concrete incentives for each responsible choice. After focusing on Palermo, Italy, the context of this case study, this chapter provides a detailed description of the TrafficO_2 model. Specifically, the chapter deals with the analysis of a selected sample of users among Palermo University students who commute daily to their respective University departments on campus. Starting from the modal split of the actual situation (Status Quo scenario), another behavior scenario (Do your right mix) is designed and promoted to encourage users to create a better mix of existing mobility means and reduce the use of private vehicles powered by combustibles. The first test that was performed confirmed the reliability of the initiative.

INTRODUCTION

The development of urban sustainable design models in the field of transportation is becoming more connected to social sciences and ICT technologies (Patier & Browne, 2010). The main reason is given by the ability to rapidly understand the different motivations that lead people (Moore, 2011) and, therefore, the various social categories that define the urban community, to choose one urban transport system over another (Nasrudin & Nor, 2013). In fact, starting from this analysis it should be possible to develop solutions with the purpose of implementing and inducing more sustainable behavior regarding the use of urban transport. It is often argued that the choice of urban

DOI: 10.4018/978-1-4666-8282-5.ch018

transport system depends on the circumstances and on current infrastructure; therefore, it is hard to develop convincing tests in the field without literally building different infrastructure (Urry, 2012). Also, habits are a key element for defining transport models, and this makes individual behavior changes very difficult to implement.

It is not only a question of top-down policies (Singapore Land Transport Authority, 2008), but it is also about bottom-up dynamics guided by citizens' lifestyles, daily habits and the ways they perceive the city itself (Gatersleben et al., 2013).

According to the "Urban Metabolism" metaphor (Pincetl et al., 2012), in order to improve the "body's" performance, we should operate upon the "nervous system", i.e. on the people that too often 'use' the city improperly (Wamsler & Brink, 2014). Alongside the projects for retrofitting the urban systems (Luederitz et al., 2013) and the new urban transport policies (de Freitas Miranda & Rodrigues da Silva, 2012), research projects that tie "transport-values-communication-behaviors" are rapidly growing (Næss, 2013).

In this field, the possibility of using new media technologies to influence citizens' urban transports habits (Gal-Tzur et al., 2014) is gaining attention. Smartphones or better information systems through personal mobile technologies, specifically, seem to be the most effective due to the real time one-to-one dialogue with citizens (Brazil & Caulfield, 2013). In fact, through these inexpensive devices it is already possible to implement applications similar to the ones researchers are developing to help civic administrators to manage traffic (González et al., 2013). Mainly, the companies working on this issue are "for profit" private enterprises which support the citizens that are increasingly becoming "consumers" of the services the city offers or "prosumers" of their community (Izvercianu et al., 2014).

However, other attempts have been made and guided by "non-profit" organizations and research centers which use similar instruments, such as Social Computing (Kwai Fun & Vagner, 2008), and aim to develop social innovation projects with the goal of improving the environment and energy policies (Souza Santos & Kahn Ribeiro, 2013). Nowadays, in fact, some proposals are being made to address the theme of urban mobility in an alternative way, through technology social innovation tools. The Italian Ministry of Education and Research is directly funding some of these projects through the 2012 tender "Smart Cities and Communities and Social Innovation". This proves how relevant this policy is today, which links research, innovation and immediately usable tools to deal with issues concerning cities.

This chapter will discuss the description of urban mobility for the city of Palermo and the application context for these research programs. This will be followed by a detailed analysis of the "TrafficO_2" project (developed by one of the authors) and the current timeline of the development process in its second year of implementation. The discussion will focus on the models used, on the first results and on the limitations of this approach. The perspectives for further experimentation will be discussed as well.

BACKGROUND

The Mobility System for the City of Palermo

Many researchers and designers are attempting to create "tailor-made" solutions for behavior-changing projects that are able to improve energy efficiency policies. Following this main research approach, the city of Palermo was chosen because of the interesting situation the city has been facing for the past few years.

Palermo is the fifth biggest city in Italy in terms of population (654,858 inhabitants in the urban area and 1.2 million in the metropolitan area); its population density is 4,270 inhabitants / km^2 in an area of 159 km^2. Palermo, like many other cities in Italy, faces severe traffic problems on a daily basis. By consulting the data from (ISTAT, 2012) regarding the average speed of vehicles and of public transportation in urban areas, it is evident that the city is one of the slowest in Italy, as reported in Table 1.

The average vehicle density in Palermo is the second highest in Italy after Naples, and, taking into consideration the fleet of vehicles, most of them are considerably old. This data is probably sufficient to make a first consideration regarding the complex scenario the city is facing.

The city's bus network extends for 341 km (Comune di Palermo, 2013) and is served by one of the oldest bus fleets in Italy, 50% of which belongs to the Euro 0[2] class (buses built in 1992) and Euro 1 class (buses built in 1995). The city has a good distribution of bus stations (14.7 stations/km^2 – 3.6 points higher than the average of the 15 largest Italian cities), but the supply (2,400 seats per km per inhabitant) is well below the Italian average (about 3,500 seats). Nevertheless, in 2010 the number of passengers increased by +18% in comparison to the previous year and, according to the data collected by AMAT, only 51% of the fleet was actually used (in 2010 only 287 of the 560 available buses were in circulation).

Palermo does not currently have an underground transport system (the project is currently being developed). In the past few years, the city has integrated an urban rail transport system (running at a frequency of every 30 min – service provided by Ferrovie dello Stato) with three lines, 12 stations and able to cover 16 km in the urban area. Finally, a tram network (including 3 lines) is currently being built and is destined to serve the suburban districts of the city.

Palermo has also been experimenting for the past 5 years with a car sharing system, which includes 43 car parking spaces, 31 parking areas and 900 users. Unfortunately the efficiency of the system is limited due to the fact that people are forced to return the cars to the same station they were picked up.

Other policies to improve sustainable mobility systems have never been concretely pushed by the city's administration. The ISTAT data shows, for example, that the length of the bike lanes is apparently coherent with the national average (13.3 km per 100 km^2 compared to 15.4 km per 100 km^2); however, most of the lanes are on the pedestrian sidewalks, interrupted by gazebo, trees and accesses to garages.

Until 2007 the city was last among the 15 biggest metropolitan cities in Italy per territorial density for areas with limited traffic. Recent data show a rapid increase in the number of square meters of areas with limited traffic, however there are few limitations (for example in commercial streets there are no restrictions).

The civic administrators seem to use policies on the prices of parking as the only instrument to face mobility problems. The number of "pay and display" parking areas has increased with vertical growth (the variation from 2000 to 2007 was greater than 1,500%), with a clear dual objective: to incentivize the use of cars and to bring money

Table 1. Average speed of urban vehicles, density and average age

	Rome	Milan	Naples	Turin	Palermo	Genoa
Car average speed (km/h)	23	22	21	26	20	25
Public Transport average speed (km/h)	12	12	10	13	12[1]	15
Cars per 1000 inhabitants	565	529	597	565	590	461
Cars older than 8 years	49%	47%	48%	72%	60%	51%

into the city coffers. Nevertheless, this strategy doesn't seem to work very well as the pay and display parking areas are all mainly within the already heavily congested city center, and the interchange-based parking lots are few and far between and too poorly connected to the city center to be effective. This situation, obviously, doesn't encourage people to use alternative public transportation services, as shown clearly in Table 2.

This data is proof of the urban conditions in Palermo. Years of local transport "non-policies" have pushed the city into a worrying paradox: even if the typical distances traveled are brief (22 km per day – 3 km less than the average of the six major cities in Italy), horrible traffic jams are part of the daily routine yet citizens still prefer to travel by car and unbelievably dream of a future with more parking lots and less public transportation (Cittalia, 2009). This means that urban traffic, besides being an infrastructure problem, is, more than ever, a great social and cultural problem.

These general characteristics of the city's transport system can be traced back to the fact that Palermo was the only city, among the three major Italian metropolitan areas, without an Urban Plan for Mobility for many years. This gap was only bridged in March 2013 when the Municipality adopted a new General Urban Plan for traffic management that will focus on the following specific mobility themes:

- Plan for improving pedestrian mobility (which foresees the definition of squares, streets, routes, pedestrian areas and limited traffic areas);
- Plan for improving local urban and suburban public transportation (defining specific lanes, interchange hubs, reorganization of existing lines and frequency);
- Plan for reorganizing urban and suburban private transport circulation (which will focus on a general traffic scheme, issues due to city crossing and street priority types);
- Plan for the rationalization of parking areas (which will indicate the parking streets that also define the fee system).

A NEW INSTRUMENT FOR PALERMO'S SUSTAINABLE MOBILITY: TRAFFICO$_2$

As many thinkers on cities and citizens' behaviors, from Kevin Lynch (Lynch, 1960) to Peter Calthorpe (Calthorpe, 2011), have stated, cities are communities made of people, and if we aim to effectively change the urban conditions, we have to change how people perceive cities, how they interact with them, how they act upon them. All over the world designers are dealing with studies that aim to define new tools to face urban traffic

Table 2. Modal split (source: authors' elaboration on 2009 ISTAT data)

	Rome	Milan	Naples	Turin	Palermo	Genoa
Cars	28%	17%	19%	27%	37%	21%
Urban bus/tram/ trolleybus	14%	16%	14%	16%	9%	19%
Metro	13%	16%	15%	7%	*[3]	5%
Extra-urban bus	2%	3%	6%	3%	2%	3%
Motorbikes/scooters	8%	6%	10%	3%	12%	12%
Bicycles	2%	8%	3%	7%	3%	2%
Taxi	2%	2%	3%	3%	2%	1%
Train	4%	3%	5%	3%	4%	6%
Walking	27%	27%	25%	31%	31%	33%

issues in the old and consolidated cities. Many believe that we need to change citizens' views towards mobility systems, simply focusing on and improving "human transit".

The social sciences have already crossed into the urbanism field, but today new information technologies are making this communication faster and more productive. American private enterprises such as Nuride (http://nuride.com), Zimride (http://www.zimride.com/) and LYFT (https://www.lyft.com/), and European enterprises like moovel (https://www.moovel.com/en/US/), Mo-bility (http://www.mo-bility.com/mo/home.html) and Covivo (http://www.covivoturage-dynamiq.eu/) are quickly moving the debate on changing cities by switching their attention from the necessary modifications of the urban structure (the hardware) to the changes that can be induced by working on citizen behavior and the urban communities' habits (the software).

All of these initiatives try to stimulate the community to change its bad habits, fostering more responsible behavior through the use of smartphone apps. Essentially, the idea is to trigger a social and cultural change with the "dialog" tool provided by social media technology and, possibly, create a new service and, therefore, a new market. In fact, the majority of the above-mentioned projects were all developed by start-ups. This area of computer science is called "Social Computing". The idea behind it is: *deep impact on global economy and on social organization can be obtained by fast connections (with low cost devices), modular contents and shared computing resources*.

The planning process for the city of Palermo is stimulated over time along the same lines of the other well-known experiments implemented at international level, by a series of bottom-up initiatives. The Italian Ministry of University and Research is funding the three most relevant ongoing projects that are being implemented in Palermo with EUR 4 million. These applied research projects aim to stimulate local communities to promote more responsible behavior in the field of urban mobility through the aid of smartphone applications (Kamal et al., 2014). The three teams of researchers that won the fellowship grant are multidisciplinary groups with a "social entrepreneur" approach: Muovity, CityFree and TrafficO_2. Each of them concentrates their efforts towards the large urban community of the University of Palermo. This choice was made based on the selected target to test their products: young and curious students are probably the best social community on which to experiment projects that, driven by new technologies and social media, aim to changing their mobility behavior (Vinci & Di Dio, 2014).

The TrafficO_2 project is developing a mobile app that acts as a Decision Support System (DSS) (Kwai Fun & Wagner, 2008), which aims towards more sustainable mobility, providing concrete incentives for each responsible choice made by the users. The idea is to combine the interests of the two complementary actors involved in the urban traffic scene: the community of workers and the local retail businesses (Porta et al., 2009). The local businesses that subscribe to the platform (as sponsors) become the stations of a new type of transport system that fosters travel by *walking*, *biking*, *public transportation*, *vehicle pooling* and *car sharing*. The final objective is to reduce traffic and pollution through an educational game (Filsecker & Hickey, 2014) by proposing an equal deal for everyone: prizes in exchange for behavior that is respectful of the environment.

Each user describes their mobility habits and preferences on transport choices through a survey and the app then proposes more sustainable choices on a daily basis. This means that the commuter will immediately be able to see the total improvement towards more sustainable mobility, and can therefore be more motivated to change. The app experience sees the user choose from between the closest Local Business Station (LBS) or Star Sponsor Station (SSS) as a starting or arrival point. Afterwards, the route will be displayed according to the different types of journey: walking, biking, public transportation or with a shared vehicle. Each choice will give a list based on the time, environmental costs, economic costs and calories burned (see Figure 1).

Furthermore, each choice will be worth a certain amount of so-called O_2 points (a virtual currency), which users will earn and use towards prizes, transforming TrafficO_2 from a DSS for sustainable and environmentally-friendly trips into a game citizens can play. The possibility of earning O_2 points is also influenced by a weather factor. This option is created in an attempt to promote more sustainable systems on cloudy and rainy days. Obviously more sustainable trips will award more points, as reported in Table 3, and users will also be able to increase their O_2 points by challenging their friends through the website or via the mobile app and playing with the engagement content made available by the sponsors.

The smartphone technology, besides the software interface, provides motion recognition for the trips (Dernbach & Das, 2012), differentiated with a high level of accuracy if the user is walking, biking or travelling by car. This is possible due to the sensors within the devices and the microprocessors that, through a specific algorithm, overlap the GPS position information and accelerometer, and detect the motion system (Manzoni et al., 2011). The recognition of the transport system and its validation is the most interesting innovation and, for users and sponsors, represents a fundamental guarantee for the rules of the game.

The system rewards walking trips more than biking due to the business model behind the app. Travelling by walking, in fact, offers the opportunity to engage with more local businesses and therefore contributes to providing more advertising information and higher revenues for the network of sponsors. The points awarded for the other transport systems are proportional to their emissions and environmental impact on urban mobility. Fundamentally, TrafficO_2 is a platform based on value exchange: for each responsible choice there is an existing tangible market value, and each choice will advertise and communicate information regarding the sponsors. There are several reasons to encourage people to change their habits: "extrinsic reasons" such as rewards

Figure 1. User interface. From left to right: overview of the city map with local businesses (blue icons) and sponsors (gold icons); information about the selected trip (by biking and walking); the last image represents a selected trip that, if completed, will give the user 157 O_2 points

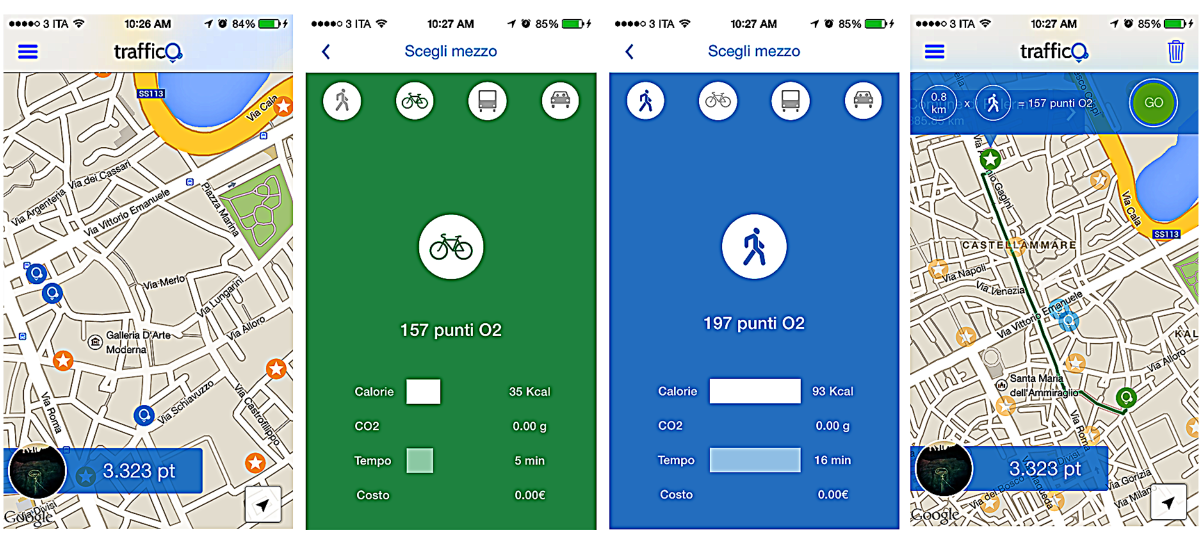


Table 3. O_2 points divided per mobility system

	O_2 Points per Kilometer	Cloudy Weather Factor	Rainy Weather Factor
Walking	5	1.5	3
Biking	4	2	4
Public Transport	3.5	1.5	2
Car-pooling 2 seats	0.5	1	1
Car-pooling 3 seats	1.0	1	1
Car-pooling 4 seats	1.5	1	1
Car-pooling 5 seats	2.0	1	1
Motorcycle-pooling	0.5	1	1
Car-sharing	1.5	1	1

and challenges, and "intrinsic reasons" such as calorie information, the cost of the selected route, the carbon footprint (Pierce et al., 2003), etc. All in all, by combining information on mobility, advertising and a game, TrafficO_2 aims to provide commercial motivations and an emotional input to push people towards change.

The system is designed to create value for the citizen, the city and the network of businesses and sponsors that actively participate to the project. In fact:

- Communities that currently need a mobility manager will face traffic issues through a DSS for sustainable mobility.
- Local businesses that want to invest in innovative advertising and seek geo-marketing analysis will receive visibility by becoming stations in the system, which will allow them to obtain detailed information on their customers and on their products.
- Sponsors that want to provide clients with positive values and, at the same time, receive the analysis of their target, will be recognized for their social efforts by financing the prizes, and will receive detailed feedback on the products and on the users that interact with them.

During the testing phase, TrafficO_2 does not foresee any financial burden on its business partners. This is a non-profit business model with the final objective of guaranteeing an entirely free service to citizens, covering the administrative costs through the economic contribution of the partners. As of today, the communities involved in the project are asked to use internal resources to make users aware of the functions of the system, and the initial Local Stations and Sponsor Stations are only asked to provide discounts and prizes for users.

It is worth noting that TrafficO_2 was recently selected by the EU campaign "Do the right mix" (http://www.dotherightmix.eu/) as a remarkable action for mobility and the future of cities.

In the following sections we will describe the TrafficO_2 model, or rather the *status quo* scenario (Scenario 0) and then a new and desired scenario (Scenario 1) that improves the previous one.

Building up the *Status Quo* Scenario

In December 2013, 30 students were selected through a workshop (involving three different University of Palermo departments: Computer Science, Design and Marketing Communication), and the first test of the assumption was performed.

The objective of this first test was to verify the user experience and the questionnaire structure necessary to build the modal split for each individual involved. During the month of April 2014, the test sample was increased, involving 77 students from other departments as well. Naturally, the sample is not yet representative of the entire population in Palermo, nor of the entire student body (about sixty thousand students), however it is quite significant in terms of a behavioral approach for research purposes. Through the information collected from the survey, it was possible to determine the length of the routes travelled daily (one way) for each user to reach the given university department, and consequently the total impact of the sample on these distances.

The sample was subdivided into five different categories based on the distance covered to reach the university departments (Table 4). These distances were obtained through an analysis provided by the ©Google maps tool.

Where

$$L_{i,trip} = D_{0i,w} + D_{0i,b} + D_{0i,t} + D_{0i,c} + D_{0i,m} + D_{0i,cp} + D_{0i,mp} + D_{0i,cs} =$$

$$(M_{0i,w}\ L_{i,trip}) + (M_{0i,b}\ L_{i,trip}) + (M_{0i,t}\ L_{i,trip}) + (M_{0i,c}\ L_{i,trip}) + (M_{0i,m}\ L_{i,trip}) + (M_{0i,cp}\ L_{i,trip}) + (M_{0i,mp}\ L_{i,trip}) + (M_{0i,cs}\ L_{i,trip}) \quad (1)$$

and D_{0i} is the daily distance (km) to reach the university by the different types of transportation *w*, *b*, *t*, *c*, *m*, *cp*, *mp* and *cs* that respectively indicate: walking, biking, public transport, car, motorcycle, car-pooling, motorcycle-pooling, car sharing. M_{0i} are the percentages of usage of the different mobility transportation systems as from the survey.

Table 5 contains the available transport systems, as obtained by the survey. The questionnaire also allowed us to evaluate the modal split of the sample (Table 6), which represents Scenario 0.

It is interesting to note how almost 50% of the testers are bike owners or have bikes available to them, but only 5% of them use this mobility system to commute to the University. Furthermore, it is relevant that almost 50% of the sample could easily use the local public transport system (based on the distances of their houses to the bus stops), nevertheless only 22% use it frequently.

The car ownership rate (Table 5) increases almost in line for distances from 3 to 10 km. The low rate of car owners (14%) for distances between 10 and 20 km is justified by the fact that suburban area residents belong to the blue-collar working class with generally mid to low salaries. On the other hand, the value of the car owners belonging to the group E (50%) is justified by the distance itself that entails the need to use private transportation, also given by the general public transport situation in Sicily. This system is the most used (50% adding those who only use cars and those who travel by carpooling), even if the average is constant at 35% for distances above five kilometers.

As far as the environmental performances for Scenario 0 goes, the total carbon emissions (E) for each daily one way trip (L_{trip}) were calculated with the following equation:

Table 4. Distribution of the five University commuter classes

SCENARIO 0	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
ΣL_{trip} (km)	34,7	75,8	156,1	89,7	164,7	521
% Sample	30%	26%	27%	9%	8%	

Table 5. Available mobility systems for the five university commuter classes

SCENARIO 0	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
Motor disabilities	0%	0%	0%	0%	0%	0%
Bicycle owners	22%	65%	38%	14%	50%	39%
Bicycle available	4%	15%	24%	14%	0%	13%
Car owners	9%	15%	43%	14%	50%	23%
Car available	52%	60%	57%	71%	50%	57%
Motorcycle owners	13%	30%	14%	29%	17%	19%
Motorcycle available	9%	15%	19%	0%	0%	12%

Table 6. Scenario 0: modal split of the five university commuter classes

SCENARIO 0	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
$M_{0,w}$ - Walking	62%	32%	0%	0%	0%	9%
$M_{0,b}$ - Biking	12%	20%	4%	0%	0%	5%
$M_{0,t}$ - Public transport	10%	13%	25%	19%	34%	22%
$M_{0,c}$ - Car	5%	9%	34%	35%	35%	27%
$M_{0,m}$ - Motorcycle	0%	14%	12%	9%	3%	8%
$M_{0,cp}$ - Car-pooling	6%	9%	17%	26%	25%	23%
$M_{0,mp}$ - Motorcycle-pooling	5%	4%	8%	12%	3%	6%
$M_{0,cs}$ - Car-sharing	0%	0%	0%	0%	0%	0%

$$E_0 = E_{0,t} + E_{0,c} + E_{0,m} + E_{0,cp} + E_{0,mp} + E_{0,cs} \quad (2)$$

where

$$E_{0,t} = \sum_{i=1}^{n} D_{0i,t}\alpha_t \quad (3)$$

$$E_{0,c} = \sum_{i=1}^{n} D_{0i,c}\alpha_c \quad (4)$$

$$E_{0,m} = \sum_{i=1}^{n} D_{0i,m}\alpha_m \quad (5)$$

$$E_{0,cp} = \sum_{i=1}^{n} D_{0i,cp}\alpha_{cp} \quad (6)$$

$$E_{0,mp} = \sum_{i=1}^{n} D_{0i,mp}\alpha_{mp} \quad (7)$$

$$E_{0,cs} = \sum_{i=1}^{n} D_{0i,cs}\alpha_{cs} \quad (8)$$

and for the i^{th} commuter, n is the total number of the individuals in the sample, and α (g/km) are the CO_2 emission factors for each type of transportation.

The α emission factors (Table 7) were calculated using the COPERT software (Copert, n.d.; Kioutsiouski et al., 2010). The bus data were scaled for the average number of passengers in a vehicle (80), the result for carpooling was defined starting from the result for cars and divided by 2.5 average passengers, the result for motorcycle-pooling was defined starting from the result for motorcycles and divided by the 2 possible passengers.

The output data for the Copert software is described in Table 8, where the authors define car, motorcycle, bus type and average speeds, based on the average results of the tester sample and AMAT data.

All of the performances of Scenario 0 are described in Table 9.

It is easy to note that the behavior with the greatest impact refers to the last three categories (C, D, E), with an average impact of E_0/km 120g/km. Furthermore, despite the fact that less than 44% of the sample population lives in these areas, their impact accounts for more than 91.8% of the overall emissions, indicating the generally bad environmental behavior of these groups.

It is worth noting that the emissions of each class are coherent with the values reported in Table 5.

In order to improve the performances of the *status quo* scenario, a possible change is suggested to each user through the frontend of the app. This requires designing a new and desired scenario (Scenario 1) to use with the purpose of proposing alternative choices to the users. This scenario aims at improving the modal split without completely excluding trips by car or motorcycle, but encourages commuting by walking, biking, public transport and vehicle-sharing to reduce emissions. The app calculates and communicates the personal potential improvement to challenge users to enhance their personal environmental performance. For this reason Scenario 1 was called "Do your right mix".

Designing the Do Your Right Mix Scenario

The assumptions behind this scenario are summarized by the following equation:

Table 7. Copert 4.10 results (source: elaboration by the authors based on the Copert 2014 data)

α emission factors	α_c - Car	α_t - Bus Transport	α_m - Motorcycle	α_{cp} - Carpooling	α_{mp} - Motorcycle pooling	α_{cs} - Car sharing
CO_2 g/km	238.97	22.54	80.89	95.59	40.44	238.97

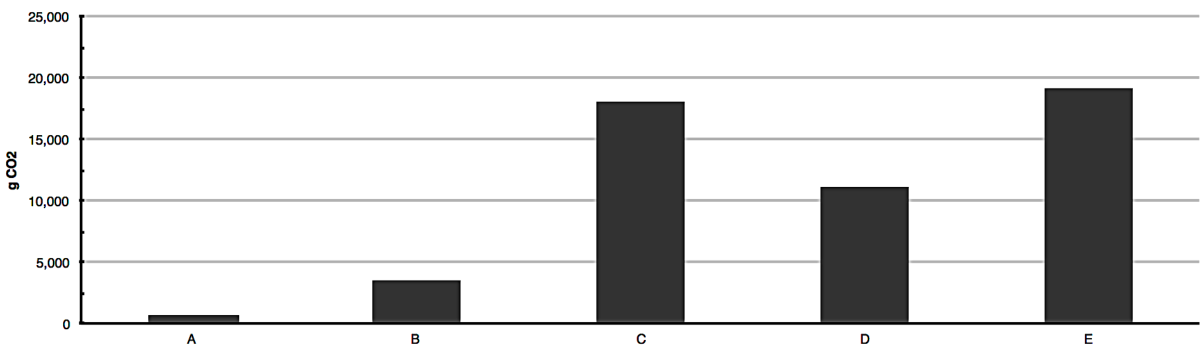
Table 8. Copert output data (source: elaboration by the authors based on the Copert 2014 data)

Sector	Technology	Class Standard	Number of Vehicles	Average Distance (km/y)	Average Speed (km/h)
Car	Gasoline 0.8 - 1.4 l	PC Euro 4 - 98/69/EC Stage2005	77	132,052	20.0
Bus	Coaches Standard <=18 t	HD Euro II - 91/542/EEC Stage II	250	41,508	12.0
Motorcycle	4-stroke < 250 cm3	Mot - Euro III	77	132,052	20.0

Table 9. Scenario 0 emissions: cumulated values of the five University commuter classes

SCENARIO 0	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
ΣE_0 (g CO_2)	760.9	3,514.30	17,996.60	11,092.20	19,052.80	52,416.70
E_0/km (g/km)	21.9	46.4	115.3	123.7	115.7	100.6
% E_0	1.50%	6.70%	34.30%	21.20%	36.30%	100%

Figure 2. Scenario 0: overview of the environmental impact of the five university commuter classes, in terms of CO_2 emissions



$$I_{1,i} = M_{i,c} + M_{i,m} = 1 - (M_{i,w} + M_{i,b} + M_{i,t} + M_{i,cp} + M_{i,mp} + M_{i,cs}) \quad (9)$$

where $I_{1,i}$, are the target percentages for improvement that the users i^{th} must reach by using more sustainable mobility systems. In other words, this percentage of improvement is given by the sum of percentages relative to the means of mobility that should be reduced (cars and motorcycles).

In Table 10 the total improvement percentages are reported for each category of the sample population. It is interesting to note that the possible improvement percentage increases up to 10 km commutes (class C); for greater distances the possible improvement percentage tends to decrease slightly, proving that classes D and E have similar mobility habits.

As far as the performance of each modal split goes, Table 11 indicates the benchmark performances, defined as the best performance (in percentage) for each category with the given transportation means: for example, referring to the biking category, the best recorded behavior among the users of class C (distance between 5 and 10 km) is 38% for commuting by bike.

In conclusion, the mission of the discussed Scenario 1 is to promote environmentally friendly mobility choices through an assumption principle based on an emulation principle: "your peers do it, why don't you?"

An algorithm was developed in order to define, by using many parameters (such as the previous habits, the availability or not of the mobility systems, the benchmark parameters etc.), the new M_1 modal split; the resulting Scenario 1 is reported in Table 12.

The if-then-else algorithm, in particular, explores in hierarchical order the different ways of reaching the goal for improvement (I_{1i}) by saturating, from time to time, the possible improvement toward more sustainable mobility means. The hierarchy of improvements included in the equation is: walking, biking, public transport, carpooling (with 5 seats occupied, the CO_2 emissions are

Table 10. Possible improvements for Scenario 1

SCENARIO 1	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km
Improvement 1	30%	60%	81%	71%	67%

Table 11. Best benchmark performances for Scenario 1: the percentages refer to the percentage of each entire trip covered by using one type of transportation

SCENARIO 0 Benchmarks	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km
B'_w - Best walking behavior	100%	80%	-%	-%	-%
B'_b - Best biking behavior	67%	80%	38%	-%	-%
B'_t - Best public transport behavior	50%	67%	67%	50%	50%
B'_{cp} - Best carpooling behavior	20%	27%	50%	60%	50%
B'_{mp} - Best motorcycle pooling behavior	17%	14%	33%	25%	13%
B'_{cs} - Best car-sharing behavior	0%	0%	0%	0%	0%

Table 12. Scenario 1: modal split for the five university commuter classes

SCENARIO 1	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
$M_{1,w}$ - Walking	67%	55%	0%	0%	0%	14%
$M_{1,b}$ - Biking	12%	20%	17%	0%	0%	9%
$M_{1,t}$ - Public transport	10%	13%	32%	22%	48%	30%
$M_{1,c}$ - Car	0%	0%	6%	21%	13%	9%
$M_{1,m}$ - Motorcycle	0%	0%	0%	2%	0%	0%
$M_{1,cp}$ - Car-pooling	6%	9%	36%	42%	37%	31%
$M_{1,mp}$ - Motorcycle-pooling	5%	4%	9%	12%	3%	7%
$M_{1,cs}$ - Car-sharing	0%	0%	0%	0%	0%	0%

similar to the motorcycle-pooling emissions), motorcycle-pooling and car sharing. If the cycle doesn't achieve the objective of target improvement, it suggests that there is still the possibility to foresee trips with an occupancy index equal to 1 (passengers per vehicle) in cars and motorcycles.

These results, compared to the ones obtained in Scenario 0 (Table 6), show a general improvement in performances, because the less sustainable means of transportation (cars and motorcycles) show a reduction: for example, regarding the subsample of class E, the use of cars is reduced from 35% to 13% according to the prediction of this scenario. The environmental impact of this first scenario due to the behavioral changes of the sample is reported in Table 13.

As shown, the current scenario allows for a CO_2 emission reduction from 100.2 to 63.3 g CO_2/km.

Table 14 compares Scenarios 0 and 1 in terms of percentages of modal split and indicates, for

Table 13. Emissions Scenario 1: cumulated values for the five university commuter classes

SCENARIO 1	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
Σ E_1 (g CO_2)	357.6	969.2	9,321.60	9,145.10	13,190.40	32,984.00
E_1/km (g/km)	10.3	12.8	59.7	102	80.1	63.3
% E_1	1.10%	2.90%	28.30%	27.70%	40.00%	

each mobility system analyzed, the improvement percentages foreseen by Scenario 1 compared to the baseline (Scenario 0).

It is worth noting that for the assumptions "Do your right mix" there is a general improvement in the entire system's performance. Meanwhile, the analysis of the components of the modal split indicates that bike (5%) and car (9%) mobility systems are influenced by higher improvements (respectively 80% and 56%), followed by public transportation and carpooling (an improvement of 36% and 35% respectively). Cars and motorcycles experience a drastic drop, recording a 67% and a 100% decrease respectively.

Figure 3 graphically represents these results, at the same time comparing each modal split for the two scenarios.

In terms of comparing CO_2 emissions, Table 15 shows that the decrease in emissions for subsample C cuts the total impact of the entire sample by 50%. It is also interesting to note that the reductions refer to the intensive values of the emissions (g CO_2/km) for all of the categories of distance, even if each one of them presents a different improvement in Scenario 1 compared to Scenario 0.

Table 14. Modal split (%): Scenario 1 vs. Scenario 0

	Scenario 0 - M_0%	Scenario 1 - M_1%	Improvement - I_1%
Walking	9	14	56
Biking	5	9	80
Public transport	22	30	36
Car	27	9	-67
Motorcycle	8	0	-100
Car-pooling	23	31	35
Motorcycle-pooling	6	7	17
Car-sharing	0	0	0

As shown in Figure 4, Scenario 1 presents already an important improvement compared to Scenario 0. It is worth noting that Scenario 1 is based on the principle of the emulation of good behavior, and could already be easily implemented in a community through a local policy.

It is also interesting to underline how this analysis makes it possible to highlight different behavior among the different classes and distances. Users belonging to class C, for example, compared to the entire sample, register an unusual waste of resources, which probably reflects the different cultural and socio-economic condition of the people that belong to such areas. This information provides a clear indication of the possible marketing strategy for the mobile application "TrafficO_2" in Palermo.

RESULTS

In order to test the models and assumptions, from 28 May to 28 June 2014 we performed the first test (with limited features) of the TrafficO_2 app. For this experimentation, testers could earn O_2 points (and win several prizes) just by walking or biking. The 77 testers were invited to download and install the app in order to start the Sustainable Urban Values (SUV) Challenge Test (http://www.traffico2.com/suvchallenge1). Almost half

Figure 3. Improvements in the modal split for the comparison between Scenario 0 and Scenario 1

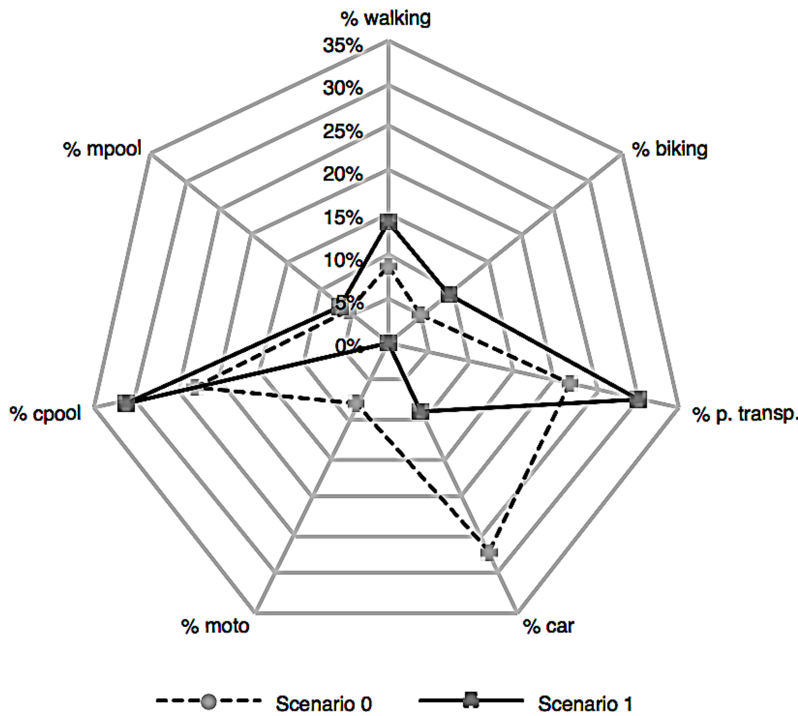
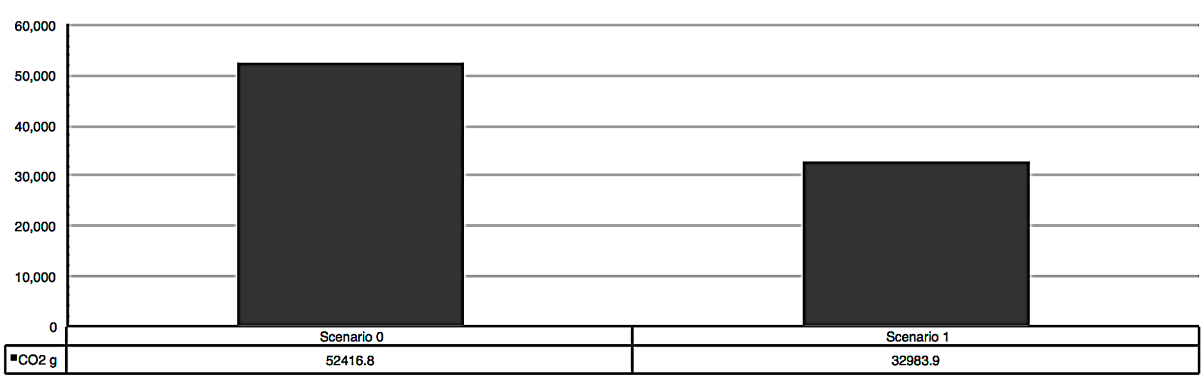


Table 15. Comparison of the CO_2 emission improvements between Scenario 0 and Scenario 1

SCENARIO 0 - 1	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km	TOT
ΣE_0 (g CO_2)	761	3,514	17,997	11,092	19,053	52,417
ΣE_1 (g CO_2)	358	969	9,322	9,145	13,190	32,984
$\triangle_1 = \Sigma E_1 - \Sigma E_0$	403	2,545	8,675	1,947	5,862	19,433
E_0/km (g/km)	22	46	115	124	116	101
E_1/km (g/km)	10	13	60	102	80	63
$\triangle_1$/km (g/km)	12	33	55	22	36	38

Figure 4. Environmental impact of the two Scenarios



of the sample downloaded the app and about 50% actively used the application. Active users are those students that used the application for sustainable trips with frequencies (F_T) superior to the ones declared through the survey (F_0).

Table 16 describes the distribution of the sample according to the five University commuter distances and the redemption of use.

Analyzing the data in Table 16, we can see that the absence of the other mobility systems (public transport and vehicle pooling mainly) probably discouraged D and E users. Because of the long distances, in fact, these two categories had more difficulty collecting points just by walking and biking.

In Figure 5 a snapshot of the server frontend interface shows which data were collected through the mobile application.

As shown in Table 17, by analyzing the gathered data we succeeded in dividing the trips according to each tester home-university department trip.

It is interesting to see how only one third of the total trips were "from" or "to" the University. This is probably due to the University examination period, when part of the SUV Test was done. During this period, in fact, students don't have to go to their departments every day. In Figure 6 the distribution of the distances traveled (km) by the active users is described.

Analyzing Figure 6 it is possible to interpret how the active testers used the mobile application. In fact, it is possible to point out how people living far from the departments (C class students) mostly use it for other routine daily trips (home-department and vice versa) and how this behavior changes and drastically inverts the proportion going towards the nearest areas. A and B class users seem to play more with the app, using it often during the day, and C students use it mainly to go to and from University.

In order to estimate the performance of the sample, it was necessary to simulate how many kilometers active users travelled (home-department and vice versa) in that period according to the answers given to the survey.

In Equation 10, F_0 represents the monthly frequency of home-department (and vice versa) trips. With this data it was possible to calculate the total distances the i[th] user will travel testing the game.

$$L_{i,TOT} = F_{0i} \, L_{i,trip} \qquad (10)$$

Table 16. TrafficO$_2$ testers' redemption

SUV Test	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km
Sample	30%	26%	27%	9%	8%
Users	16%	12%	14%	4%	4%
Active users	8%	9%	5%	1%	1%

Table 17. Number of trips recorded by the server during the Test and divided by destination and mobility system

	Walking	Biking	Total	%
Home-Department (and vice versa) trips	59	40	99	33%
Other trips	124	83	207	67%

Figure 5. Server data screenshot

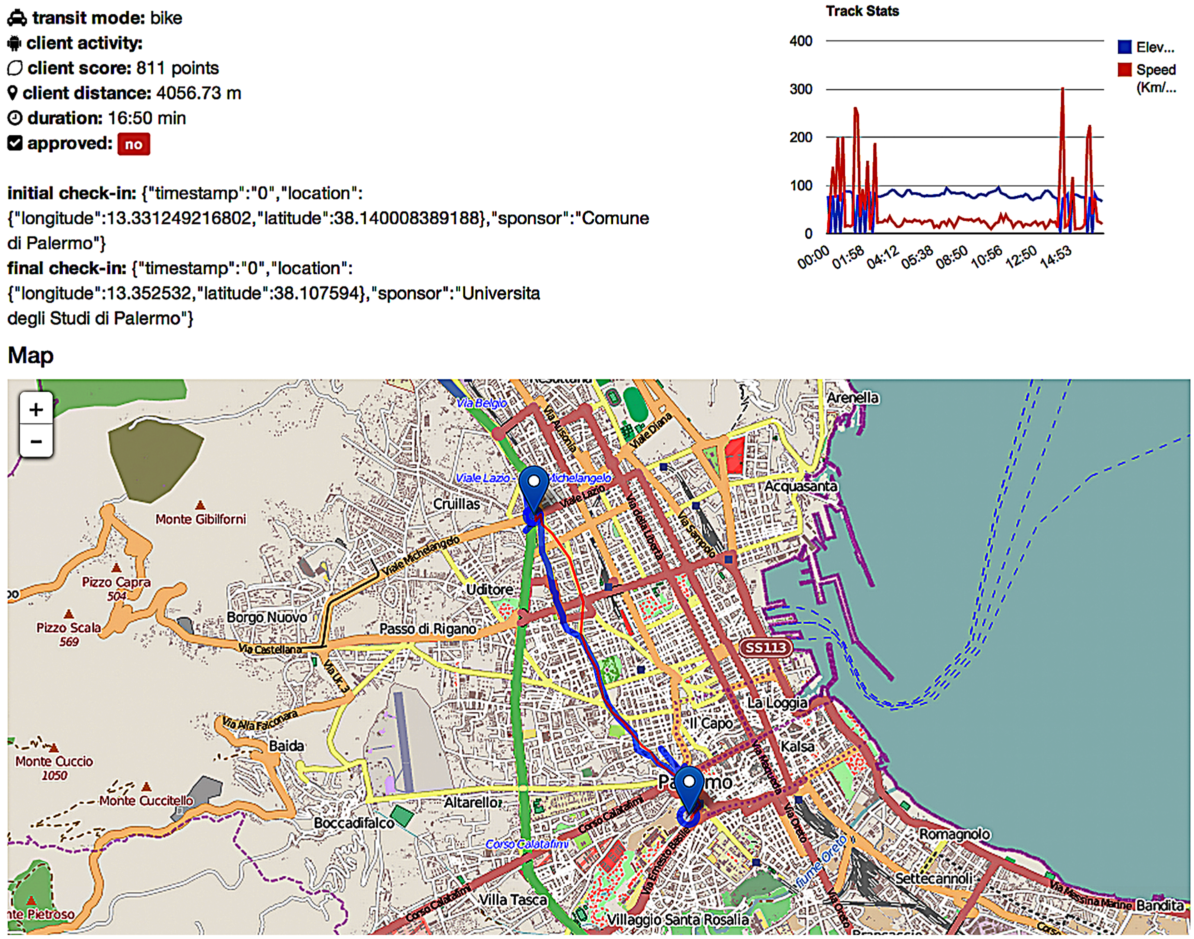
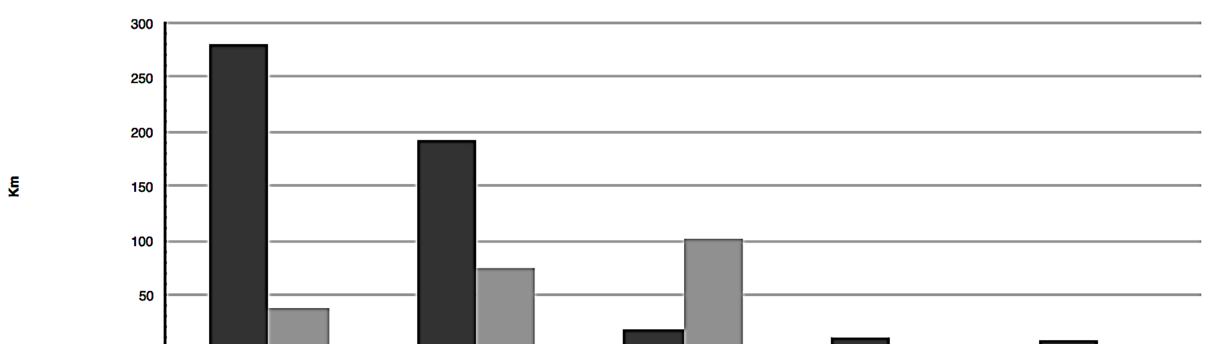


Figure 6. Five University daily commuter classes with kilometer distribution divided by destination



	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km
Other destinations	280	192.27	16.81	9.61	9.01
Home-Departments	37.34	74.34	100.52	0	0

Moreover, it was possible to calculate each mobility system frequency. The following equations explain the definition of the walking and biking frequency ($F_{0i,w}$ and $F_{0i,b}$) in (Equations 11 and 12) and how, with the walking and biking home-department (and vice versa) distances recorded ($D_{Ti,w}$ and $D_{Ti,b}$), the rate percentages of use of each mobility means ($M_{Ti,w}$ and $M_{Ti,b}$) were elaborated (Equations 13 and 14).

An if-than-else algorithm explores a comparison between the declared frequencies and the recorded ones (respectively $F_{Ti,w}$ and $F_{Ti,b}$) and therefore the different conditions each user has caused in terms of CO_2 emissions.

$$F_{0i,w} = F_{0i}\, M_{0i,w} \tag{11}$$

$$F_{0i,b} = F_{0i}\, M_{0i,b} \tag{12}$$

$$M_{Ti,w} = D_{Ti,w} \,/\, L_{i,TOT} \tag{13}$$

$$M_{Ti,b} = D_{Ti,b} \,/\, L_{i,TOT} \tag{14}$$

Table 18 presents the results of the elaborations on the distances.

Looking at Figure 7, it is evident how for longer distances $TrafficO_2$ fosters mostly the modal split toward bicycles and for shorter distances people prefer to walk.

Looking at Figure 7, moreover, it is interesting to note how the most impactful results are equally balanced between the two systems offered (walking and biking trips) and, despite the total absence of bike lanes "to", "from" and even "inside" the Palermo University Campus, $TrafficO_2$ succeeds in encouraging people to use bicycles.

Table 19 reports the CO_2 emission simulation elaborated through the data recorded during the

Figure 7. Active users' sustainable distances (home-departments and vice versa) covered during the SUV Test divided by mobility system

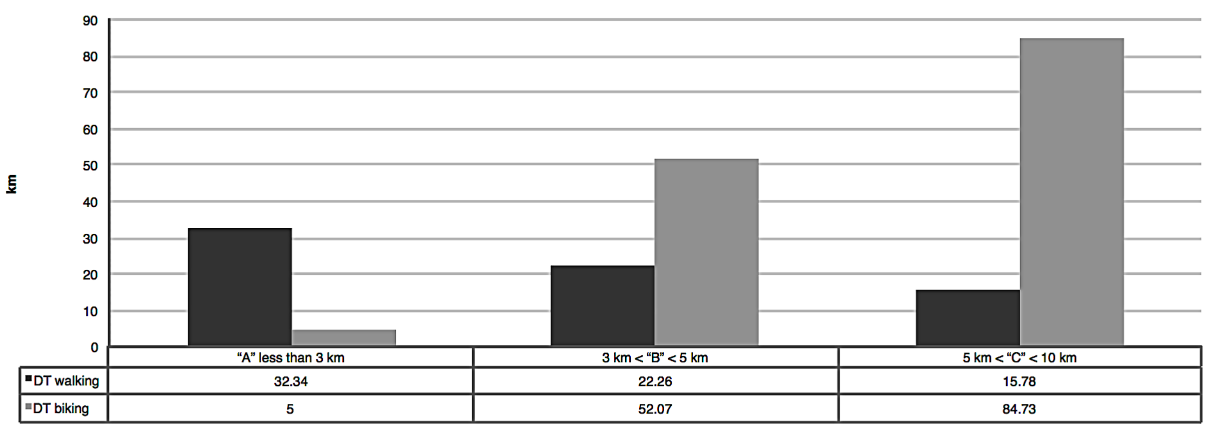


Table 18. SUV test: active users' total distances estimated and recorded

SUV Test	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	TOT
ΣL_{TOT} (km)	48.06	95.83	534.32	678.21
$\Sigma D_{Tw} + \Sigma D_{Tb}$ (km)	37.34	71.01	97.78	206.13
% ($\Sigma D_{Tw} + \Sigma D_{Tb}$)	77.7%	74.1%	18.3%	30.39%

Table 19. SUV Challenge Test: five University commuter classes, Carbon Dioxide Equivalent production

SUV Test	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	TOT
ΣE_T (g CO2)	499.82	1,236.21	30,456.07	32,192.10
E_T/km (g/km)	10.4	12.9	57.0	47.47
% E_T	1.55%	3.84%	94.61%	

SUV Test. This makes it possible to estimate the emission (E_T) generated by active users for the home-department (and vice versa) routes.

It is interesting to note how the emission rate of C class users is higher than the whole sample, accounting for almost 95% of the global CO_2 emissions due to the active users daily mobility routine.

DISCUSSION

In this section we will compare the results obtained by applying the Scenarios' assumptions to the sample with the data recorded during the first test of the mobile app. Table 20 shows the active users' kilometers calculated by the Scenario 0 data (trip lengths per declared frequencies) in comparison with what they actually recorded using the mobile app.

The comparison between past habits and the data recorded through the SUV Test, for the active users, shows positive results for each class category and particularly for C class active users (71 km more than previously declared). Comparing all of the performances, the number of sustainable kilometers increased by 84%.

In Table 21 the comparison between the SUV Test data and the simulated Scenario 1 "Do your right mix" according the data provided by the active users is presented.

It is interesting to note how the comparison shows an almost perfect match between the test data gathered by the app and the data elaborated for Scenario 1 that was based on what we called "the emulation principle".

Figure 8 graphically shows the comparison between all of the analyzed mobility habits of the active users.

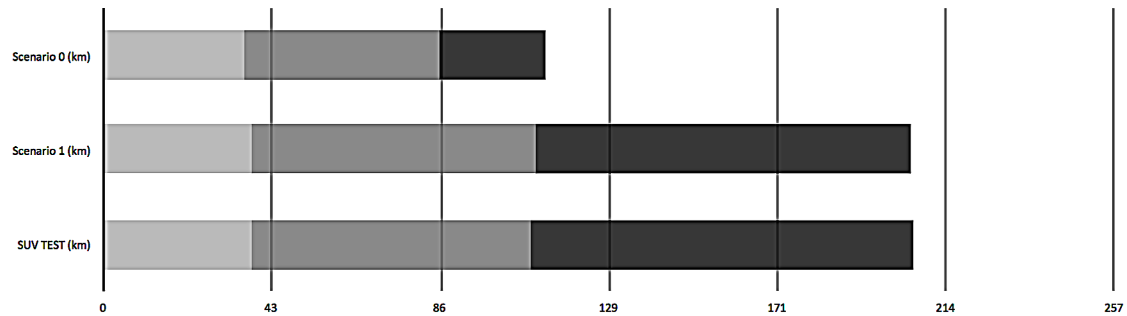
Table 20. Walking and biking active users' performance: SUV Test vs. Scenario 0

SUV Test vs. Scenario 0	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	TOT
$\Sigma D_{0w} + \Sigma D_{0b}$ (km)	35.50	49.87	26.77	112.14
$\Sigma D_{Tw} + \Sigma D_{Tb}$ (km)	37.34	71.01	97.78	206.13
$\triangle_{T0}$ (km)	1.84	21.14	71.01	94.00
$\triangle_{T0\%}$	5%	42%	265%	84%

Table 21. Walking and biking active users' performance: SUV Challenge Test vs. Scenario 1

SUV Test vs. Scenario 1	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	TOT
$\Sigma D_{1w} + \Sigma D_{1b}$ (km)	37.84	72.18	95.64	205.66
$\Sigma D_{Tw} + \Sigma D_{Tb}$ (km)	37.34	71.01	97.78	206.13
$\triangle_{T1}$ (km)	-0.50	-1.17	2.14	0.50
$\triangle_{T1\%}$	-1%	-2%	+2%	0.23%

Figure 8. Active users' sustainable distances (Home-Departments and vice versa): comparison between Scenario 0, 1 and those effectively travelled during the SUV Test



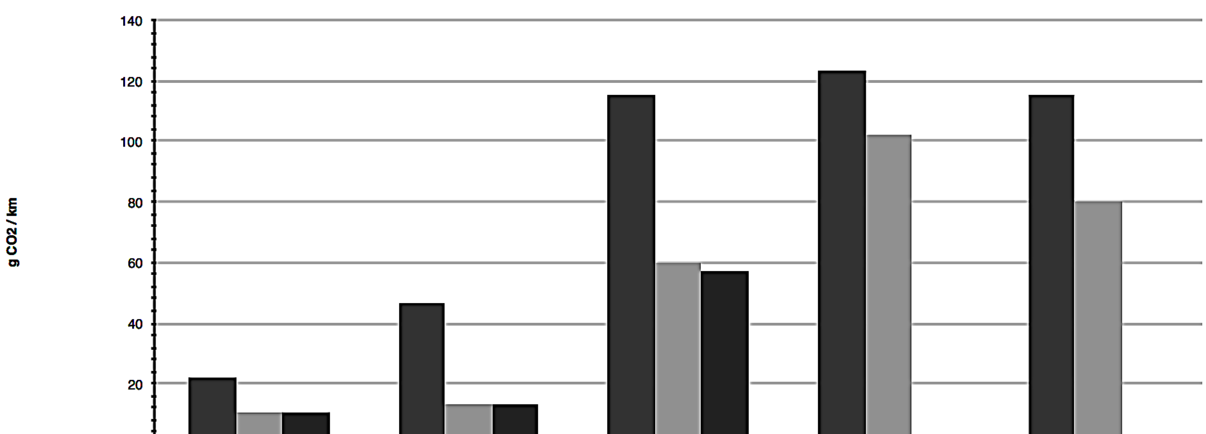
	SUV TEST (km)	Scenario 1 (km)	Scenario 0 (km)
"A" less than 3 km	37.34	37.84	35.5
3 km < "B" < 5 km	71.01	72.18	49.87
5 km < "C" < 10 km	97.78	95.64	26.77

A comparison between the two previously elaborated Scenarios (whole sample) and the data gathered through the SUV Test (active users) regarding the emissions per kilometer is elaborated in Figure 9.

It is interesting to note how, according to the data gathered, the actual performance of the active users matches with the estimated performance of Scenario 1 emissions per kilometer. Table 22 shows the carbon dioxide equivalent emission comparison between the Scenario 0 situation and the SUV Test data.

According to our calculations, it is possible to argue that the active users of the SUV Challenge Test effectively enhanced their behavior regarding sustainable mobility choices, saving almost

Figure 9. Simulated scenarios of the environmental impact comparison between the five urban areas regarding the average CO_2 emissions per kilometer (g CO_2/km)



	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	10 km < "D" < 20 km	"E" > 20 km
Scenario 0 E0/Km	21.9	46.4	115.3	123.7	115.7
Scenario 1 E1/Km	10.3	12.8	59.7	102	80.1
SUV TEST ET/km	10.4	12.9	57	0	0

Table 22. CO_2 emission improvement comparing active users' Scenario 0 simulation and SUV Challenge Test data

SCENARIO 0 - T	"A" less than 3 km	3 km < "B" < 5 km	5 km < "C" < 10 km	TOT
ΣE_0 (g CO_2)	1030	5442	23,532	30,005
ΣE_T (g CO_2)	488	1,500	12,013	14,001
$\triangle_2 = \Sigma E_0 - \Sigma E_T$	1,381	3,857	11,539	16,777
Improvement I_T	73.90%	72.00%	48.99%	54.51%

half the carbon dioxide equivalent emissions in comparison to what they declared as their previous habits.

Obviously we have to notice how this first data is still partial and how the good performances recorded are possibly related to the small sample.

FUTURE RESEARCH DIRECTIONS

Obviously, the results obtained during the first test of the TrafficO_2 mobile app with the SUV Challenge Test strongly depend on the characteristics of the city under analysis, its mobility system, its vehicular fleet and obviously by the sample under investigation. It is necessary to verify the effectiveness of the TrafficO_2 app by observing a larger sample of users, other communities and different urban contexts.

The TrafficO_2 project is in its development phase and new functions are being designed with the goal of gathering more data from the users. Detailed technical descriptions of the users' vehicles, for example, are essential to estimate the traffic CO_2 emissions, so it is easier to find the precise reduction objectives (Scenarios 1), and then further evaluate the results.

A detailed analysis of the available data will also be useful for better understanding what drives people to make their habits more sustainable (Dickinson et al., 2013). Thanks to the game's features and to the variety of relationships that the user can develop with the network of partners and sponsors (Bartolo & Mariani, 2014), it is already possible to deduce what drives each individual user, or category, when modifying or not their personal mobility habits (Gatautis & Vitkauskaite, 2014).

Furthermore, through the collected data, it will be possible to study the urban flows of the active users on the entire urban network, and therefore compare the results to the urban mobility system (Holleczek et al., 2013; Hoteit et al., 2014; Iqbal et al., 2014; Kung et al., 2014).

CONCLUSION

In this chapter we analyzed Palermo's transport system and we addressed how TrafficO_2, as a social innovation project, aims to reduce vehicle traffic flow and pollution without making any modifications on the urban structures and without applying substantial modifications to mobility policies. The strategy is to encourage, through specific information and small rewards, the workers who commute daily from home to work, to change and make their mobility habits sustainable. Therefore, we studied the behavior of a selected sample (student community from the University of Palermo) and simulated the CO_2 emissions for each trip. To motivate each individual to modify his/her behavior, we developed feasible and "tailor made" objectives for each commuter by defining a new and desired *Do your right mix* Scenario. This scenario was developed by taking into account the different distances commuters travel to reach their university departments, the availability of transportation and their habits (*Status Quo*

Scenario). Afterwards, we tested the TrafficO_2 application with reduced functions (SUV Test) and we were able to collect the first results on the effects of using the mobile app. The results, although partial, show how the behavior of the active users was successfully modified, hence reaching the objectives set by the *Do your right mix* Scenario, where the participants aim to emulate the best behavior among the registered users of the community with homogenous characteristics.

The attempt to improve the city's livability and the citizens' health seems to be more easily and effectively achievable by seeking to change bad habits through a direct dialogue with individual citizens through the use of communication technologies and social networks. Many examples come from different fields, from domestic energy consumption (Chen Lillemo, 2014; Shimokawa & Tezuka, 2014) to waste management (Lee et al., 2014), which are giving the first encouraging results.

In these times of almost "zero resources", it seems possible to improve the city's livability without implementing actions on the current infrastructure but, through information technologies, simply by inducing people to change their current bad behavior (Ceder et al., 2013). This type of approach to urban policies on mobility, furthermore, doesn't foresee the classic top-down dynamics such as road pricing or the optimization of the public transportation network, nor the creation of limited traffic zones.

For instance, this year the City of Milan published compelling results in terms of traffic reduction (City Climate Leadership Awards, 2014) due to the Limited Traffic Zone (LTZ) of 8.2 km^2 (called "Area C"). This value (49% reduction in CO_2 emissions), despite the compliance to another scale of impact, is actually lower than the result we achieved during the first small test of the TrafficO_2 mobile app, but the cost of this policy is of course higher in terms of funds and also in terms of urban impact of the necessary infrastructure needed to apply the LTZ.

The presented approach only takes into account the already available resources without modifying any aspects of them, but tries to highlight the real value they could provide citizens. A fundamental characteristic is that the approach is designed to improve the user experience through dialogue and not by changing the characteristics of the context. Furthermore, this aspect, along with the fact that smartphones are cheaper and Internet connections are rapidly improving (Pick & Nishida, 2014), should guarantee rapid scalability for the approach to different contexts (Allcott & Mullainathan, 2010; Bajardi, 2013).

The lesson learned from the analysis and experimentation is that through communication actions, which are able to establish a direct and virtuous dialogue with citizens, important results can be achieved that are comparable to the ones obtained through the implementation of coercive urban policies or expensive modifications to the urban transportation system.

ACKNOWLEDGMENT

This work was carried out within the research project "TrafficO_2 - social network for communities' urban mobility" which is funded by PON R&C 2007-2013 - Asse II, obiettivo operativo 4.2.1.3, progetto PON04a3_00451 and "RE.S.E.T. Rete di laboratori per la Sicurezza, Sostenibilità ed Efficenza dei Trasporti della Regione Siciliana", which is funded by the PO-FESR Sicilia 2007-2013 - Asse IV, obiettivo operativo 4.1.2, Linea d'intervento 4.1.2.A.

This work wouldn't have been possible without PUSH – no profit civic startup – particularly for the research done by Dott. Andrea Tosatto on data collection, and Eng. Domenico Schillaci and Eng. Francesco Massa on data elaboration and mathematical models development. We thank Michael Gerbino for the language help provided.

REFERENCES

Allcott, H., & Mullainathan, S. (2010). Behavior and energy policies. *Science*, *327*(5970), 1204–1205. doi:10.1126/science.1180775 PMID:20203035

Bajardi, M. (2013). *Designing digital regions*. (Unpublished doctoral dissertation). University of Sannio, Italy.

Bartolo, M., & Mariani, I. (2014). *Game design*. Milan, IT: Pearson.

Brazil, W., & Caulfield, B. (2013). Does green make a difference: The potential role of smartphone technology in transport behaviour. *Transportation Research Part C, Emerging Technologies*, *37*, 93–101. doi:10.1016/j.trc.2013.09.016

Calthorpe, P. (2011). *Urbanism in the age of climate change*. Washington: Island Press. doi:10.5822/978-1-61091-005-7

Ceder, A., Chowdhury, S., Taghipouran, N., & Olsen, J. (2013). Modelling public-transport users' behaviour at connection point. *Transport Policy*, *27*, 112–122. doi:10.1016/j.tranpol.2013.01.002

Chen Lillemo, S. (2014). Measuring the effect of procrastination and environmental awareness on households' energy-saving behaviours: An empirical approach. *Energy Policy*, *66*, 249–256. doi:10.1016/j.enpol.2013.10.077

Cittalia (2009). *Le città mobili. Rapporto Cittalia 2009*. Pomezia, Italy: Cittalia.

City Climate Leadership Awards. (2014). *Milan: Area C: Fewer Cars, More Public Spaces, Better Life For All*. Retrieved July 29, 2014 from http://cityclimateleadershipawards.com/2014-project-milan-area-c/?utm_content=buffer0df65&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

Comune di Palermo. (2013). *Open data*. Retrieved March 13, 2014, from http://www.comune.palermo.it/opendata.php

Copert (n.d.). Copert - The popular, straightforward and simple to use emissions calculator. Retrieved November, 30, 2014 from http://www.emisia.com/copert/

de Freitas Miranda, H., & Rodrigues da Silva, A. N. (2012). Benchmarking sustainable urban mobility: The case of Curitiba, Brazil. *Transport Policy*, *21*, 141–151. doi:10.1016/j.tranpol.2012.03.009

Dernbach, S., & Das, B. (2012). Simple and Complex Activity Recognition through Smart Phones. In *Proceedings of International Conference on Intelligent Environments* (pp. 214-221). doi:10.1109/IE.2012.39

Dickinson, J. L., Crain, R. L., Reeve, H. K., & Schuldt, J. P. (2013). Can evolutionary design of social networks make it easier to be 'green'? *Trends in Ecology & Evolution*, *28*(9), 561–569. doi:10.1016/j.tree.2013.05.011 PMID:23787089

Filsecker, M., & Hickey, D. T. (2014). A multilevel analysis of the effects of external rewards on elementary students' motivation, engagement and learning in an educational game. *Computers & Education*, *75*, 136–148. doi:10.1016/j.compedu.2014.02.008

Gal-Tzur, A., Grant-Muller, S. M., Minkov, S., & Nocera, S. (2014). The Impact of Social Media Usage on Transport Policy: Issues, Challenges and Recommendations. *Procedia: Social and Behavioral Sciences*, *111*, 937–946. doi:10.1016/j.sbspro.2014.01.128

Gatautis, R., & Vitkauskaite, E. (2014). Crowdsourcing Application in Marketing Activities. *Procedia: Social and Behavioral Sciences*, *110*, 1243–1250. doi:10.1016/j.sbspro.2013.12.971

Gatersleben, B., Murtagh, N., & White, E. (2013). Hoody, goody or buddy? How travel mode affects social perceptions in urban neighborhoods. *Transportation Research Part F: Traffic Psychology and Behaviour*, *21*, 219–230. doi:10.1016/j.trf.2013.09.005

González, A., Donnelly, A., Jones, M., Chrysoulakis, N., & Lopes, M. (2013). A decision-support system for sustainable urban metabolism in Europe. *Environmental Impact Assessment Review*, *38*, 109–119. doi:10.1016/j.eiar.2012.06.007

Holleczek, T., Yu, L., Lee, J., Senn, O., Kloeckl, K., Ratti, C., & Jaillet, P. (2013). Digital breadcrumbs: Detecting urban mobility patterns and transport mode choices from cellphone networks.

Hoteit, S., Secci, S., Sobolevsky, S., Ratti, C., & Pujolle, G. (2014). Estimating human trajectories and hotspots through mobile phone data. *Computer Networks*, *64*, 296–307. doi:10.1016/j.comnet.2014.02.011

Iqbal, M. S., Choudhury, C. F., Wang, P., & González, M. P. (2014). Development of origin-destination matrices using mobile phone call data. *Transportation Research Part C, Emerging Technologies*, *40*, 63–74. doi:10.1016/j.trc.2014.01.002

ISTAT. (2009). *Indicatori ambientali urbani 2009*. Rome, Italy: ISTAT.

ISTAT. (2012). *Dati ambientali nelle città - Mobilità urbana 2012*. Rome, Italy: ISTAT.

Izvercianu, M., Şeran, S. A., & Branea, A. M. (2014). Prosumer-oriented Value Co-creation Strategies for Tomorrow's Urban Management. *Procedia: Social and Behavioral Sciences*, *124*, 149–156. doi:10.1016/j.sbspro.2014.02.471

Kamal, N., Fels, S., & Fergusson, M. (2014). Online social networks for health behaviour change: Designing to increase socialization. *Computers in Human Behavior*, *41*, 444–453. doi:10.1016/j.chb.2014.03.068

Kioutsioukis, I., Kouridis, C., Gkatzoflias, D., Dilara, P., & Ntziachristos, L. (2010). Uncertainty and Sensitivity Analysis of National Road Transport Inventories Compiled with COPERT 4. *Procedia: Social and Behavioral Sciences*, *2*(6), 7690–7691. doi:10.1016/j.sbspro.2010.05.181

Kung, K. S., Greco, K., Sobolevsky, S., & Ratti, C. (2014). Exploring universal patterns in human home-work commuting from mobile phone data. *PLoS ONE*, *9*(6), 16. doi:10.1371/journal.pone.0096180 PMID:24933264

Kwai Fun, R., & Wagner, C. (2008). Weblogging: A study of social computing and its impact on organizations. *Decision Support Systems*, *45*(2), 242–250. doi:10.1016/j.dss.2007.02.004

Lee, D., Offenhuber, D., Biderman, A., & Ratti, C. (2014). Learning from tracking waste: How transparent trash networks affect sustainable attitudes and behavior. In *Proceedings of IEEE World Forum on Internet of Things* (pp. 130-134). doi:10.1109/WF-IoT.2014.6803134

Luederitz, C., Lang, D. J., & Von Wehrden, H. (2013). A systematic review of guiding principles for sustainable urban neighborhood development. *Landscape and Urban Planning*, *118*, 40–52. doi:10.1016/j.landurbplan.2013.06.002

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press.

Manzoni, V., Manilo, D., Kloeckl, K., & Ratti, C. (2010). Transportation mode identification and real-time CO2 emission estimation using smartphones. Retrieved November 30, 2014, from http://senseable.mit.edu/co2go/images/co2go-technical-report.pdf

Moore, S. (2011). Understanding and managing anti-social behaviour on public transport through value change: The considerate travel campaign. *Transport Policy*, *18*(1), 53–59. doi:10.1016/j.tranpol.2010.05.008

Næss, P. (2013). Residential location, transport rationales and daily-life travel behaviour: The case of Hangzhou Metropolitan Area, China. *Progress in Planning*, *79*, 1–50. doi:10.1016/j.progress.2012.05.001

Nasrudin, N., & Nor, A. R. M. (2013). Travelling to School: Transportation Selection by Parents and Awareness towards Sustainable Transportation. *Procedia -. Environmental Sciences*, *17*, 392–400.

Patier, D., & Browne, M. (2010). A methodology for the evaluation of urban logistics innovation. *Procedia: Social and Behavioral Sciences*, *2*(3), 6229–6241. doi:10.1016/j.sbspro.2010.04.033

Pick, J. B., & Nishida, T. (2014). Digital divides in the world and its regions: A spatial and multivariate analysis of technological utilization. *Technological Forecasting and Social Change*.

Pierce, W. D., Cameron, J., Banko, K. M., & So, S. (2003). Positive effects of rewards and performance standards on intrinsic motivation. *The Psychological Record*, *53*, 561–579.

Pincetl, S., Bunjeb, P., & Holmesc, T. (2012). An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning*, *107*(3), 193–202. doi:10.1016/j.landurbplan.2012.06.006

Porta, S., Latora, V., Wang, F., Strano, E., Cardillo, A., Scellato, S., & Messora, R. et al. (2009). Street centrality and densities of retail and services in Bologna, Italy. *Environment and Planning. B, Planning & Design*, *36*(3), 450–465. doi:10.1068/b34098

Shimokawa, M., & Tezuka, T. (2014). Development of the "Home Energy Conservation Support Program" and its effects on family behavior. *Applied Energy*, *114*, 654–662. doi:10.1016/j.apenergy.2013.10.007

Singapore Land Transport Authority. (2008). Land Transport Masterplan 2008: A people centered land transport system.

Souza Santos, A., & Kahn Ribeiro, S. (2013). The use of sustainability indicators in urban passenger transport during the decision-making process: The case of Rio de Janeiro, Brazil. *Current Opinion in Environmental Sustainability*, *5*(2), 251–260. doi:10.1016/j.cosust.2013.04.010

Urry, J. (2012). Changing transport and changing climates. *Journal of Transport Geography*, *24*, 533–535. doi:10.1016/j.jtrangeo.2012.05.005

Vinci, I., & Di Dio, S. (2014). Designing mobility in a city transition: Challenge from the case of Palermo. *Journal of Land Use, Mobility and Environment*, 978-988.

Wamsler, C., & Brink, E. (2014). Interfacing citizens' and institutions' practice and responsibilities for climate change adaptation. *Urban Climate*, *7*, 64–91. doi:10.1016/j.uclim.2013.10.009

KEY TERMS AND DEFINITIONS

Behavior Change: Interventions aimed to prevent risk for people health.

Decision Support System: Computer-based information system that supports organizational decision-making activities.

Gamification: The use of game mechanics in non-game contexts to engage users in solving problems.

Mobile Game: Game played on mobile phones.

Mobility Manager: He/she has to optimize the employee's systematic trips and reduce the use of private cars.

Social Computing: Intersection of social behavior and computational systems.

Sustainable Mobility: Low carbon emission mobility means.

Urban Transport: Transport in city area of all types, private and public, individual and mass.

ENDNOTES

[1] Data provided by AMAT (Palermo public transportation company).

[2] Euro 0, Euro 1, Euro 2 etc. indicate specific characteristics of vehicles regarding pollutant substances.

[3] Palermo doesn't have a metro transport system yet, a train line provided by Ferrovie dello Stato is now working as a metro service.

Section 5

Funding Smart Cities

Chapter 19
Energy Investment in Smart Cities Unlocking Financial Instruments in Europe

Francesca Romana Medda
University College London, UK

Candace Partridge
University College London, UK

Gianni Carbonaro
European Investment Bank, Luxembourg

ABSTRACT

The intense pressures being brought to bear by the increasing diversity in European urban development patterns call for innovative funding mechanisms to promote smart sustainable urban development, most notably in the energy sector. Currently in Europe, various policy initiatives support sustainable urban development through financial engineering mechanisms operating at municipal and regional scales. The objective of this chapter is to review the main financial mechanisms focusing on energy, and in particular on urban investments committed to a highly energy-efficient, and low carbon, economy. Within this framework we assert that, in order to achieve the EU sustainable urban development outcomes, specific European financial instruments will need to be considered as viable key investment options. The structure and operational features of European Financial Instruments are explored here in the case of the Urban Development Fund implemented in London. We also discuss the importance of ESCOs and crowdfunding as essential funding sources for community energy projects, and suggest that European policy should recognise their importance.

INTRODUCTION

The level of urbanisation in Europe at present is approximately 75%, and it is expected that, from 2020 onwards, Europe will stabilise at an urbanisation level of over 80%. Against this trend, a wide range of initiatives have been carried out in the EU context focussing on the pivotal role of cities and urban areas in addressing challenges associated with sustainable resource use and management of climate change impacts. However, due to continuing, and in some cases accelerating

DOI: 10.4018/978-1-4666-8282-5.ch019

urban growth, cities are being forced to evolve in order to address the growing pressures on their infrastructures. One path within current urban development is that of the Smart City.

Smart Cities are key in the movement toward a more carbon-neutral economy because they foster the innovation necessary to invent and adapt technologies that help with resource management by reducing consumption (Caragliu et al., 2011; Manville et al., 2014). Part of their 'smartness' derives from the so-called spatial intelligence of cities, which arises from the combination of technology, agglomeration economics and individual and collective intelligence (Deakin & Allwinkle, 2007; Mitchell, 2007). But this new urban paradigm, which interweaves economics and environmental, cultural and social aspects with technological advances, still has hurdles to overcome, foremost of which are insufficient financial resources and appropriate business models. Smart City projects often have difficulty raising investment for their implementation because they tend to occur over long time frames and thus offer delayed returns on their investment; furthermore, such projects must often apply new and potentially unproven technologies. Furthermore, given that Smart City projects often involve interconnecting technologies, they are likely to face significant risk exposure in the form of operational and market risk. In our view, the formulation of new types of business models for attracting investment therefore still needs to take place.

Analysis of the financial resources and tools to support urban sustainable smart development is a paramount endeavour, particularly in light of the present economic slowdown, and also in emerging economies where banking and lending markets are still unfolding. Over the years, many financial tools have been designed to tackle the funding constraints within the public sector, and above all to attract private investors. However, such tools have frequently offered short time horizons for investments and a 'silo view' in relation to their financial returns. Whereas it is possible in Smart Cities to direct investments toward production, such as photovoltaic and thermal technologies, and consumption, such as the use of smart meters, but in both cases smart energy investments require the commitment of authorities, operators and citizens in the design and construction of effective services and infrastructures through integrated action.

Most greenhouse gas (GHG) emissions emanate from urban regions and therefore the response of city authorities to climate change and energy consumption is critical both to the achievement of climate and energy targets, and in the design and implementation of sustainable investment strategies. In particular, the increasingly popular use of Infrastructure and Energy funds for financing smart city projects is endorsed by scholars who agree that they are especially suited to support sustainable growth. Nonetheless, when we consider urban investment in smart energy, these financial tools have some limitations. For example, Infrastructure and Energy funds generally lack an integrated approach and thus do not cohere with city development strategies. Therefore, in recent years, major support and interest has been building with regard to financial instruments which can fill the gap in the market of funds dedicated to sustainable urban development. Within this framework, the objective of this chapter is to review the main financial mechanisms that have been designed to achieve highly energy-efficient, low carbon economies in cities.

We begin by investigating two main mechanisms, the first of which is well-established in the energy market, the Energy Service Companies (ESCOs); the second mechanism can be regarded as the new generation of investment funds: crowdfunding and community energy projects. Both types of tools can help to compensate for some of the shortfall in public investments directed towards smart energy projects. However, we argue that in order to achieve sustainable urban development outcomes, foster the development of Smart City technology, and invest in the transition to a low carbon and climate-resilient economy, the establishment of urban/regional funds for energy is a key investment option, especially when applied in conjunction with grass roots efforts such as crowdfunding. We therefore turn our attention to these financial instruments in section II, especially those implemented by the European Commission. We examine in detail in the next section the application of the Urban Development Fund (UDF) promoted by the European Commission's JESSICA Initiative dedicated to energy investments in London. In the current financial context we are quick to notice that public sector urban investment is often affected by budget constraints, and private sector investment is subject to speculative and short-term approaches and limited delivery capacity, particularly in mid-sized and smaller cities. Thus, the overarching aim of this review is to underscore the need for a range of financial tools that will effectively increase the availability of financial resources and funding mechanisms for sustainable long-term urban transformation.

ENERGY INVESTMENTS AND CITIES

Fusaro and Vasey (2006) have noted that "the energy industry has literally been transformed into the 'hot' investment sector," and over the years many elements have contributed to this dramatic rise in value of the energy sector. The global recession starting in 2007 has exacerbated the problems already underlined with the fall of Enron in late 2001 and the dispersion of energy merchants in 2002; that is, we are now confronted with a significant lack of investment in infrastructure across the energy sector dating back to the energy price drop in 1986. This condition is certainly worsened by the surge in global demand for energy arising from rapid economic growth taking place in China and India. These different pressures have generated a pronounced rise in energy price and volatility, and thus the interest in and need for alternative forms of energy and energy-efficient investment.

Energy is the world's largest business, with over $4 trillion in annual trade. For example, the natural gas market on its own exceeded $400 billion in trade in 2011, and over 450 hedge funds with energy and environmental interests are now active in the market. Environmental financial commodities were worth about $41 billion in 2007, but since then have doubled year on year (RAB Capital, 2011). In this dynamic landscape it is noteworthy that the energy financial model in place for many years has recently begun to diversify to include venture capital, institutional investors, equity investments, and others. Furthermore, these new participants in the energy market are increasingly aware that, in their arena, environmental issues are impacting significantly on energy investments, project costs, regulation, and risk.

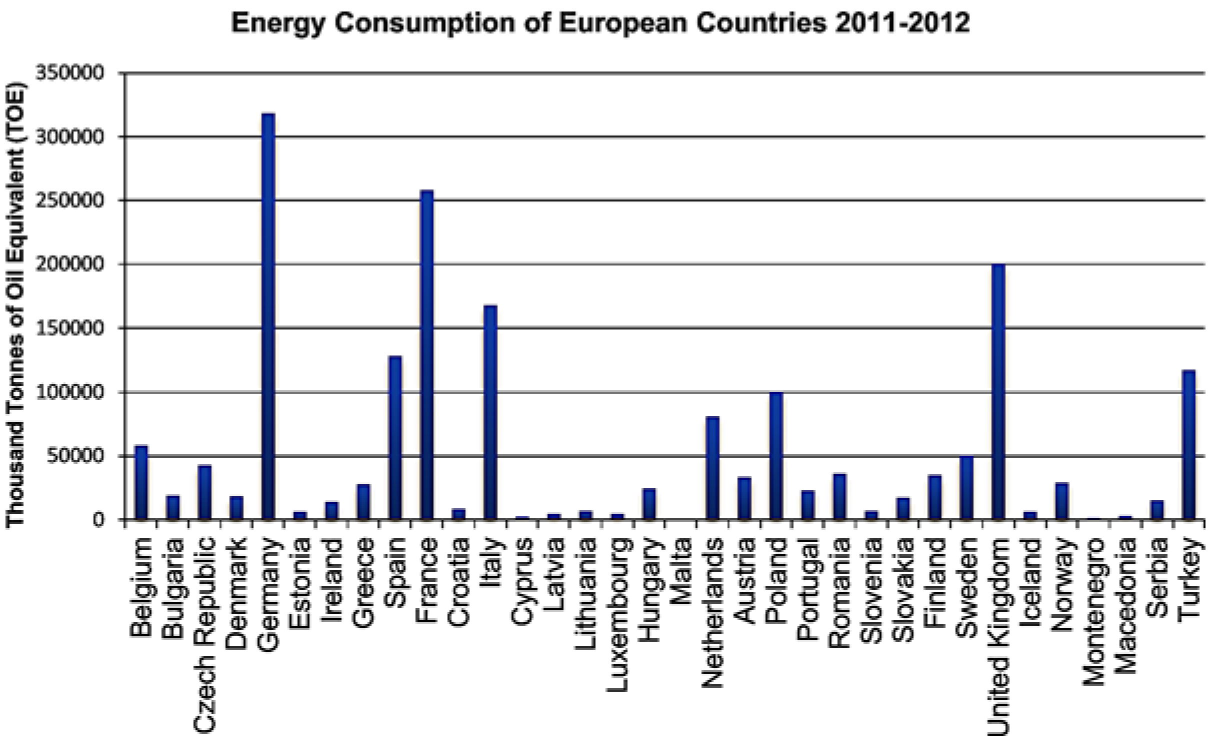
In spite of innovation and according to observers, the energy and environmental market is still regarded as relatively immature. The market is nevertheless complex because it is inherently volatile and capital-intensive due to its physical aspects and to the fact that it is routinely subject to risks, particularly in relation to volume risk. Furthermore, energy investments are characterised by a number of phases of development that each require different financial methods to reach completion. For instance, un-tested technologies are better suited for venture capital tools, whereas bonds and pension funds are appropriate in the operational refinancing phase of the application of mature technologies (OECD, 2011). Given this background, the financial resources now required for the energy sector vastly exceed the capabilities of public finance, particularly in the current state of EU government finance. The need is greater than ever for an investment landscape that can foster private intervention, promote competition and catalyse innovation.

In tables 1-4 and figures 1-3 we give a graphic review of a sample of European nations' energy investment levels (production) and growth rates, European Union energy consumption at national and city levels, and EU renewable energy pro-

Table 1. Sample of EU national investment in energy production (Source: Pew Charitable Trusts, 2014)

	Investment ($bn)				5 Year
	2010	2011	2012	2013	Growth Rate
France	4	5	4.3	2.9	-8.3%
Germany	41.2	30.6	22.8	10.1	-8.2%
Italy	13.9	28	14.7	3.6	-10.4%
Spain	4.9	8.6	2.9	0.4	-54.5%
Turkey	1.2	0.3	1.4	0.8	-7.7%
UK	3.3	9.4	8.3	12.4	18.3%
Rest of EU28	13.4	11	16.3	11.5	-5.8%

Figure 1. Overview of energy consumption in European countries (Source: Eurostat, 2014a)



duction. The tables depict two important trends. First, as observed by the European Renewable Energy Council (2014), is that "all forecasts on the expansion of renewable energy have consistently been surpassed." In fact, the contribution of renewables in Europe has increased over the years in line with greater controls being imposed on nations' dependency on fossil fuels and on the possible detrimental impacts in relation to economic growth and energy pricing upsurge, in particular. The second trend is that investments in energy have become extremely strategic. The EU imports over 55% of its energy needs, costing in 2012 €400 bn (European Commission, 2013). In 2011, according to the International Energy Agency (International Energy Agency, 2013)

Table 2. Energy consumption in European countries (Source: Eurostat, 2014a)

Overall Energy Consumption in Units of Thousand Tonnes of Oil Equivalent (TOE)					
	2009	2010	2011	2012	2011-2012 Average
EU28	1,694,898.0	1,759,729.4	1,699,485.2	1,683,494.6	1,691,489.9
Belgium	57,086.8	61,036.5	59,668.5	56,320.8	57,994.7
Bulgaria	17,504.1	17,769.8	19,089.9	18,233.3	18,661.6
Czech Republic	42,412.7	44,727.8	43,225.6	42,783.5	43,004.6
Denmark	19,186.7	20,146.7	18,747.5	18,140.6	18,444.1
Germany	317,157.9	333,674.7	317,122.6	319,451.4	318,287.0
Estonia	5,356.8	6,157.1	6,187.6	6,120.7	6,154.2
Ireland	14,794.3	15,129.8	13,987.5	13,847.3	13,917.4
Greece	30,476.1	28,731.0	27,796.3	27,748.9	27,772.6
Spain	130,394.9	129,868.5	128,212.4	127,294.6	127,753.5
France	259,541.1	267,121.6	257,841.7	258,392.6	258,117.2
Croatia	8,702.3	8,561.2	8,530.5	8,118.3	8,324.4
Italy	168,925.8	174,763.0	171,992.0	163,215.4	167,603.7
Cyprus	2,813.7	2,728.2	2,678.5	2,509.3	2,593.9
Latvia	4,509.4	4,765.7	4,376.4	4,537.6	4,457.0
Lithuania	8,467.0	6,779.5	6,999.8	7,084.5	7,042.2
Luxembourg	4,360.4	4,637.0	4,559.8	4,454.2	4,507.0
Hungary	25,158.7	25,811.0	25,104.4	23,551.1	24,327.8
Malta	871.0	953.2	918.7	837.3	878.0
Netherlands	81,046.0	86,611.7	80,212.3	81,775.4	80,993.9
Austria	32,324.7	34,599.8	33,649.9	33,654.9	33,652.4
Poland	94,744.8	100,918.2	101,219.9	97,974.4	99,597.2
Portugal	25,068.0	24,281.5	23,612.9	22,199.8	22,906.4
Romania	35,554.7	35,799.6	36,558.4	35,370.3	35,964.4
Slovenia	7,056.2	7,226.2	7,280.8	7,004.5	7,142.7
Slovakia	16,779.7	17,864.3	17,402.4	16,701.5	17,052.0
Finland	33,854.9	37,068.4	35,508.6	34,088.2	34,798.4
Sweden	45,454.2	50,783.1	49,711.7	49,792.7	49,752.2
United Kingdom	205,295.1	211,214.2	197,288.6	202,291.3	199,790.0
Iceland	5,503.7	5,499.7	5,875.6	5,845.3	5,860.5
Norway	29,593.3	33,227.6	28,085.2	30,288.7	29,187.0
Montenegro	1,018.7	1,176.5	1,131.6	1,069.1	1,100.4
Macedonia	2,758.8	2,833.6	3,083.4	2,946.3	3,014.9
Serbia	15,223.7	15,590.8	16,139.4	14,474.9	15,307.2
Turkey	100,030.9	106,866.0	113,878.9	119,775.6	116,827.3

Figure 2. Overview of renewable energy production in European countries (Source: Eurostat, 2014b)

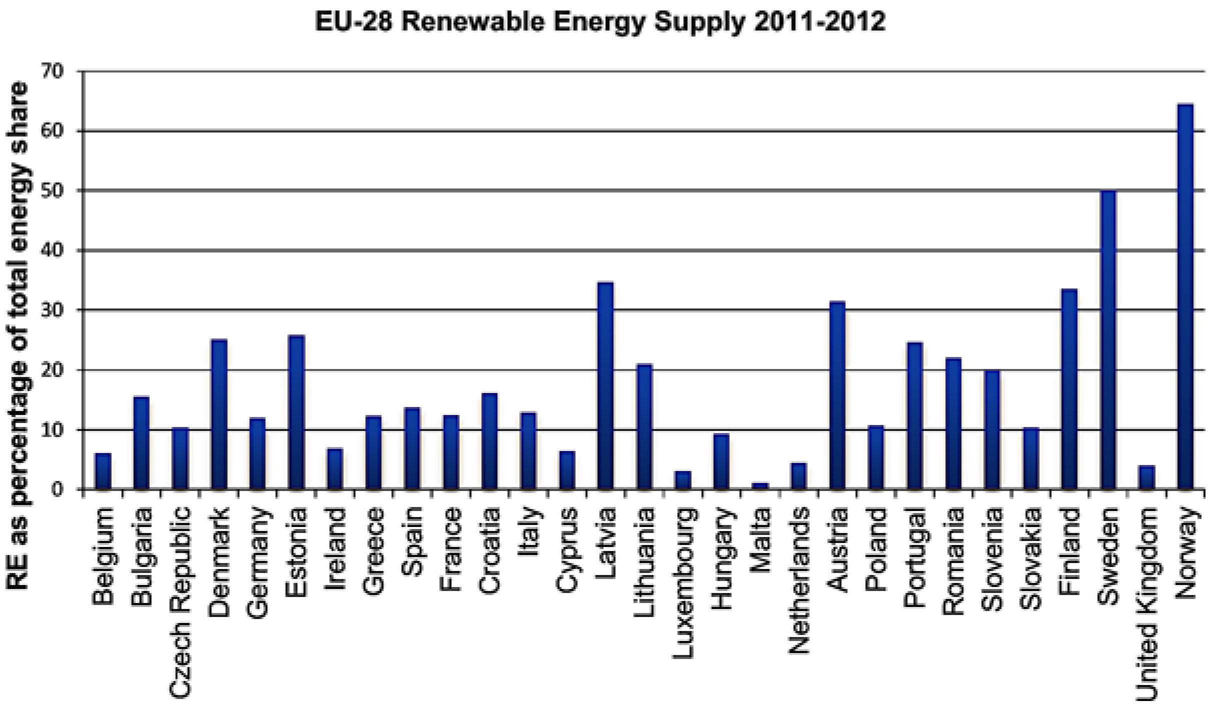


Figure 3. Overview of energy consumption in European cities (Source: Siemens, 2009)

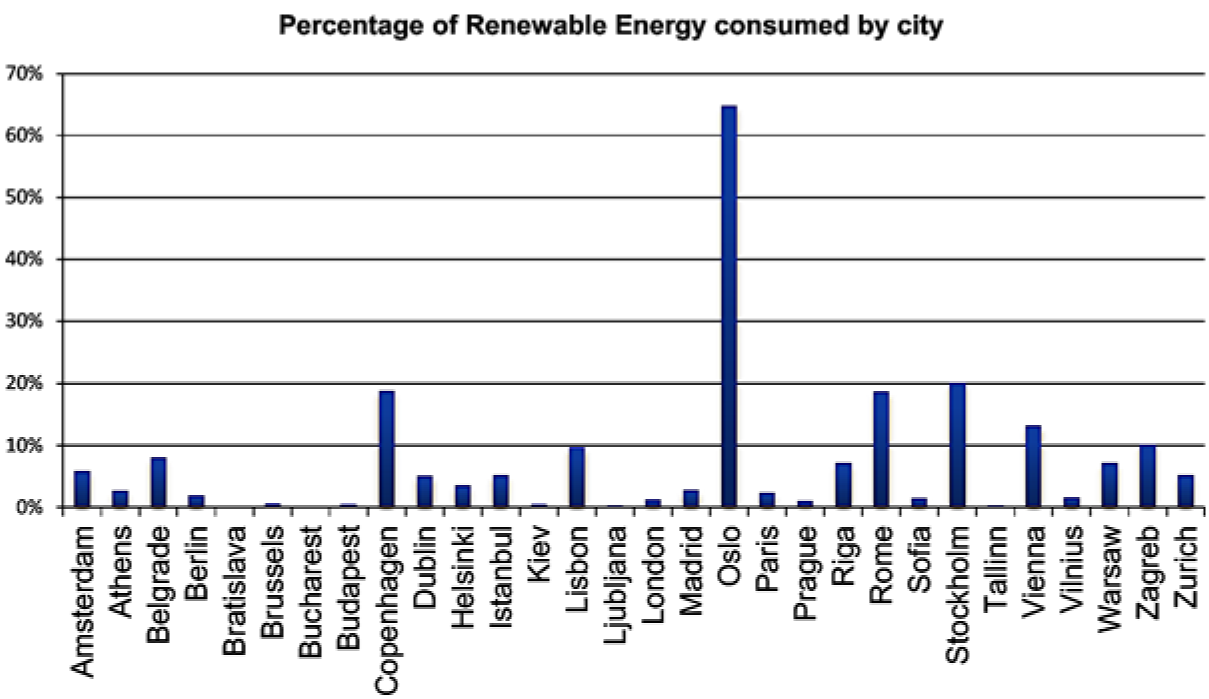


Table 3. Renewable energy production in European countries (Source: Eurostat, 2014b)

	2009	2010	2011	2012	2011-2012 Average
EU-28	11.9%	12.5%	12.9%	14.1%	13.5%
Belgium	4.6	5.0	5.2	6.8	6.0
Bulgaria	12.4	14.4	14.6	16.3	15.5
Czech Republic	8.5	9.3	9.3	11.2	10.3
Denmark	20.4	22.6	24.0	26.0	25.0
Germany	9.9	10.7	11.6	12.4	12.0
Estonia	23.0	24.6	25.6	25.8	25.7
Ireland	5.2	5.6	6.6	7.2	6.9
Greece	8.5	9.8	10.9	13.8	12.3
Spain	13.0	13.8	13.2	14.3	13.7
France	12.2	12.7	11.3	13.4	12.4
Croatia	13.1	14.3	15.4	16.8	16.1
Italy	9.3	10.6	12.3	13.5	12.9
Cyprus	5.6	6.0	6.0	6.8	6.4
Latvia	34.3	32.5	33.5	35.8	34.7
Lithuania	20.0	19.8	20.2	21.7	21.0
Luxembourg	2.9	2.9	2.9	3.1	3.0
Hungary	8.0	8.6	9.1	9.6	9.3
Malta	0.4	0.4	0.7	1.4	1.1
Netherlands	4.1	3.7	4.3	4.5	4.4
Austria	30.4	30.8	30.8	32.1	31.4
Poland	8.8	9.3	10.4	11.0	10.7
Portugal	24.5	24.2	24.5	24.6	24.6
Romania	22.6	23.2	21.2	22.9	22.1
Slovenia	18.9	19.2	19.4	20.2	19.8
Slovakia	9.3	9.0	10.3	10.4	10.3
Finland	31.2	32.4	32.7	34.3	33.5
Sweden	48.2	47.2	48.8	51.0	49.9
United Kingdom	3.0	3.3	3.8	4.2	4.0
Norway	64.8	61.2	64.6	64.5	64.5

energy efficiency investments around the world have amounted to $300 bn, and in Europe in order to meet the EU 2020 targets, many countries have quickened their pace of development in the renewable energy market. During the 2014-2020 programming period, the EU allocated €23 bn of European Structural and Investment Funds for the transition to a low carbon economy. However, as stated by the Energy Efficiency Financial Institution Group (2014), energy renewable investments need tailored financial tools because "they are not repaid via clearly identified receivables, there may

Table 4. Energy consumption in European cities (Source: Siemens, 2009)

City	Country	CO2 per Capita	Energy Consumption	Renewable Energy
		(tonnes)	(GJ)	(percentage)
Amsterdam	Netherlands	6.7	74.5	5.8%
Athens	Greece	5.9	88.8	2.7%
Belgrade	Serbia	3.9	41.1	8.0%
Berlin	Germany	6.6	77.7	1.8%
Bratislava	Slovakia	5.1	82.8	0.0%
Brussels	Belgium	3.9	86.9	0.6%
Bucharest	Romania	5.2	72.1	0.0%
Budapest	Hungary	5.8	98.9	0.4%
Copenhagen	Denmark	5.4	80.6	18.8%
Dublin	Ireland	9.7	156.5	5.1%
Helsinki	Finland	6.0	88.6	3.5%
Istanbul	Turkey	3.3	36.2	5.1%
Kiev	Ukraine	4.1	87.2	0.5%
Lisbon	Portugal	7.5	48.7	9.7%
Ljubljana	Slovenia	3.4	105.9	0.2%
London	UK	5.8	78.0	1.2%
Madrid	Spain	4.1	80.3	2.8%
Oslo	Norway	2.2	94.8	64.8%
Paris	France	5.0	96.7	2.3%
Prague	Czech Repub	8.1	67.2	1.0%
Riga	Latvia	4.0	69.2	7.1%
Rome	Italy	3.5	84.6	18.7%
Sofia	Bulgaria	4.3	80.7	1.4%
Stockholm	Sweden	3.6	104.9	20.1%
Tallinn	Estonia	6.8	89.6	0.2%
Vienna	Austria	5.2	78.7	13.2%
Vilnius	Lithuania	4.6	62.9	1.5%
Warsaw	Poland	6.3	49.8	7.1%
Zagreb	Croatia	6.7	10.1	10.1%
Zurich	Switzerland	3.7	94.8	5.1%

be uncertainty over the predictability of revenue streams, and using on-bill financing, they may not be linked to a single identified individual or legal entity."

For our purposes here, we concentrate on cities, as this is where the most innovative and successful energy programmes have been implemented and carried out (ARUP, 2011). A city will often strive for consistency between its mission and the ways it achieves that mission and may, over time and through concerted efforts, attain transparency, predictability and longevity of its government programmes. These qualities are certainly necessary in order for investors to participate in energy projects (Croce, 2011), and this is especially relevant for investments that operate primarily in renewable energy, clean technology, environmental technology, and energy efficient solutions.

When compared to national governments, city authorities often have greater political will, capacity, and flexibility to establish incentives and guarantees to make the risk-return profile of energy investments more appealing to investors. Many cities have followed a strategy in which they deploy private capital incrementally in order to allow the energy market to mature and further expand opportunities for green investment as an asset diversification strategy (see, for instance, the recent growth of Green Pension Funds). Alternative methods of urban financing have been developed in Europe over the last decade to include, for example, Effizienzhaus in Germany, which in 2010 had a commitment of over €8.5 billion to 100.000 loans, contributing to over 40% of German targets on climate protections for the housing sector (KfW, 2011). Nonetheless, some financial instruments which have been developed and tailored for specific urban realities are difficult to export to other urban areas without encountering drawbacks. In this context and with the aforementioned caveat, in the next section we review different financial initiatives as interesting tools that can also be adapted widely to smart city advancement. We will explore the main characteristics of this approach in the next two sections and examine the case of London as a model, where financial instruments developed from the EU JESSICA Initiative have been implemented to support London's green agenda.

ENERGY SERVICE COMPANIES: ESCOs

As energy service companies, ESCO businesses specialise in energy efficiency solutions. These usually privately held companies create revenue through energy savings resulting from providing clients with more efficient equipment. The energy savings are used to pay for the new equipment and services of the ESCO, usually through an Energy Performance Contract (EPC), which overcomes the initial financial constraints of energy efficiency projects by paying off investment costs through the future energy savings due to reduced energy consumption. ESCOs often perform energy efficiency services for municipal, university, hospital and school buildings (the so-called MUSH sector), generally for customers who spend at least $1 million per year on energy (Sclafani, 2008), since a sizeable economy of scale is required to generate sufficient energy savings with which to finance a project, such as smart city initiatives.

The ESCO business model operates on the principle that if a project does not save the customer money by saving energy, then the ESCO will not receive revenue from that project. Working with ESCOs can help overcome the upfront costs needed for energy efficiency (EE) projects by financing the project against future cost savings attributed to reduced energy consumption. By sharing the risk in energy projects, ESCOs "offer an opportunity to curb increasing energy demand and control CO_2 emissions while capturing market benefits by decreasing clients' energy costs and making profit for themselves" (Bertoldi et al., 2006).

The services that ESCOs provide include retrofitting, power generation, energy savings consultation, and risk management. The most common EE Smart City projects involve upgrading heating, ventilation and air conditioning installations (HVAC) and boiler rooms. At the municipal level, ESCOs can develop district heating systems and install less energy-intensive street lighting. In factories and other industrial facilities, ESCOs can also help with refurbishment and improvements in heat recovery (Bertoldi et al., 2006). Okay and Akman (2010) found that "in richer countries ESCOs find more opportunities in the commercial and municipal sectors, and fewer opportunities in the industrial sector."

Given their main function to promote energy efficiency and reduce power consumption, ESCOs are inherently green. Moreover, according to BASE, increased efficiency in energy production and management can help to reach up to 58% of CO_2 emissions reductions worldwide before 2030; this technological aim pertains especially to Smart Cities because EE technologies are "the fastest, highest impacting and most cost-effective way of reducing greenhouse gas emissions, particularly in densely populated areas" (BASE, 2006).

Although the definition of the ESCO term varies somewhat around the world, they all tend to have similar business models that involve taking on the risk of EE projects while simultaneously benefiting from energy savings. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on Energy End-use Efficiency and Energy Services, defines an ESCO as "a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria" (European Parliament, 2006). Satchwell (2010) and others define an ESCO as "a company that provides energy-efficiency-related and other value-added services and for which performance contracting is a core part of its energy-efficiency services business" (Hopper et al., 2007; Larsen et al., 2012). In a performance contract, the ESCO guarantees energy and/or Euro savings for a project, and in so doing, ESCO compensation is linked in some fashion to the performance of the project.

Energy efficient Smart City projects carried out by an ESCO can broadly be financed in one of three different ways: through customer self-financing, by the customer sharing the risk with the ESCO, or by the ESCO taking on the risk entirely. In self-financing, the customer pays for the project using internal funds, which may include a loan backed by an ESCO savings guarantee; here the customer takes responsibility for all the financial risk related to the project. In the other two methods of energy project financing, the ESCO takes on the risk of the energy savings project through third-party financing (TPF). In these situations funding is provided by a financial institution rather than internal funds of either the customer or the ESCO. The financial institution can have a stake in the ownership of the equipment used in the project, or it can assume the rights to any energy savings through an Energy Performance Contract (EPC) (Institute for Energy and Transport, 2003). Through third-party financing, some or all of the EPC is based on the ESCO's projected energy savings (Energy Charter Secretariat, 2003). By guaranteeing energy savings from the project, the ESCO enables TPF by assuring the bank that the project will generate a positive cash flow in order for the savings to effectively service the debt. The savings guarantee also reduces the perceived risk of the smart city project, thereby allowing access to financing at lower interest rates (Institute for Energy and Transport, 2003).

In all three methods of funding, the ESCO guarantees a project's energy savings and performance, and this is especially interesting with regard to the smart cities approach. But in the case of an Energy Performance Contract (EPC), the energy savings gain will finance the project and provide the financial basis for securing a loan to cover the capital. From this standpoint there are two well-known ways to structure an EPC: In the *guaranteed savings* model the loan goes onto the client's balance sheet, but in the *shared savings* model the loan goes onto the ESCO's balance sheet. In the guaranteed savings model, the ESCO takes on the performance and design risk, but not the credit risk, which instead is carried by the client (Bertoldi et al., 2006). Usually the value of energy savings is guaranteed down to a certain base price sufficient to meet debt service obligations. Whereas in the shared savings model the ESCO is obliged to carry the full project risk, including credit risk. The shared savings model is often of particular interest for MUSH projects, since these projects are kept off their own balance sheets. Typically, the payments to the ESCO are linked to energy prices (Poole & Stoner, 2003).

Although an Energy Performance Contract through an ESCO enables energy projects to get financed by transferring risks away from the end-user, there are some disadvantages, one of which is the loss of flexibility arising from having to sign a long-term contract with the ESCO. It can also be difficult for EPC-based financing to successfully navigate public procurement rules (Energy Charter Secretariat, 2003). Particularly in the public sector, procurement rules in the tendering process put ESCO project development at a disadvantage, as emphasis is placed on initial investment costs rather than (possibly lower) life-cycle costs (Bertoldi et al., 2007). Accounting rules such as International Financial Reporting Standards (IFRS) are also seen as barriers to ESCO-funded projects, and financial institutions are more amenable to asset-based as opposed to cash flow-based lending (Marino et al., 2011).

The difficulty of ESCO projects to get through the procurement process is cited in the literature as a main barrier to entry, but there are others, including low familiarity with the benefits of EE, the lack of a project financing culture, the historically low price of electricity, and concerns about the adoption of new technologies. One often underrated barrier to entry is the negative response from some utility companies that is based on the fear of decreased revenues (Vine, 2005); this type of refusal corresponds to the most fundamental impediment to investment in renewable energy and EE, which is "the fact that energy prices do not reflect the real costs of carbon and other environmental externalities" (BASE, 2006).

The economic crisis of 2008 has obstructed ESCOs' access to funding because public bodies have tended to defer large capital investments, such as retrofits, partly due to the contraction of credit markets; the knock-on effect of reduced credit has compelled financial institutions to impose shorter contract periods, ultimately leading to smaller (Smart City) projects (Satchwell, 2010). According to Vine (2005), other trends impacting on the ESCO market include the removal of energy subsidies, institutional privatisation, and international competition. There has also been significant ESCO market consolidation through buyouts and mergers which, according to Satchwell (2010), will reduce the number of players in the Energy Performance Contract field.

While most ESCOs are privately held companies, there are some examples of public ESCOs, particularly in Europe (Bertoldi et al., 2007). In these arrangements the energy agency will typically act as an ESCO in order to facilitate EPC for municipal projects with high social importance. These public ESCOs tend to be more willing to accept higher risk or smaller profit than private ESCOs, which helps to fund EE smart projects in cities that might not otherwise find sufficient investment.

In addition to the advantages of traditional EE projects, ESCO finance can also help to pay for the installation of renewable energy systems, since they fall in line with the ESCO remit of lowering energy usage. At present, renewable energy technologies are likely to be more expensive due to the lower energy density they are able to exploit when compared with traditional fossil fuel sources. However, through the combined effects of lessening energy demand and the novel ways in which ESCOs can finance energy systems through EPCs, the realised energy savings could for example be used to finance photovoltaic arrays or geothermal heat exchangers in situations where financing these technologies through traditional capital expenditure methods would be too expensive for the customer (Sclafani, 2008).

CROWDFUNDING AND COMMUNITY ENERGY

Although ESCOs can be used to stimulate the development of large-scale energy projects for smart cities, the fact remains that many smaller projects still struggle to find funding. As larger entities, ESCOs as well as other financial instruments such as On-Bill Repayment and the Energy Service Agreement, can step in to support projects of sufficient size where economies of scale are used to keep capital costs as low as possible. In particular, these entities place emphasis on funding smart energy projects that are part and parcel of integrated urban development plans, thus the projects supported are at the municipal scale. However, in the meantime, a major branch of the smart city paradigm has been an increase in decentralisation and democratisation of urban infrastructure, and this trend includes energy efficiency and production projects. Smaller community-based projects that do not fit into larger development plans, for example, may therefore find it easier to obtain financing either through crowdfunding (Rossi, 2014) or by setting up local community energy cooperatives.

For instance, given that less than 15% of energy in the UK is generated from renewable sources (DECC, 2014), there is strong social and political impetus toward the development of new renewable energy (RE) smart projects. As part of the drive to create clean energy sources, energy efficiency (EE) projects are on politicians' and planners' agendas, but these projects frequently involve new smart energy technologies, so they too are facing funding shortages. However, it is noteworthy that the rise of crowdfunding is becoming a viable source of paying for smaller RE/EE projects in cities, thus ensuring that successful community energy projects are implemented.

The decentralised community energy model has already been used to good effect in Germany and Denmark. Over 50% of Germany's renewable energy is provided by community energy, and 10% of its wind power is generated by 'burgerwindparks' (citizen windfarms). Similarly, in Denmark, over 20% of their electricity is generated by wind power, much of which is locally owned (Toke, 2005). Part of the successful uptake of community energy in these countries can be attributed to tax incentive schemes and subsidies, alongside national energy policy decisions to encourage the growth of community RE projects. Currently in Denmark, an onshore wind project developer is obligated to offer ownership (at cost) of at least 20% of a project to investors within a range of 4.5 km. The offers should be at cost price. Denmark plans to double its wind power capacity by 2020, so this policy guarantees increases in the number of public stakeholders participating in community energy schemes (Hvelplund, Möller, & Sperling, 2013).

Community energy has in the past been financed by participants located within the local area, since they are the beneficiaries of the project. However, the proliferation of crowdfunding means that people who are interested in investing in smart energy projects no longer need to formally join a local co-operative group, but rather can contribute through peer-to-peer lending or by buying a stake in the project (Heeter & Mclaren, 2012; Julian & Olliver, 2014). This is particularly relevant to energy projects in smart cities because it enables citizens to invest easily in local energy projects, and in so doing, lowers the barriers to entry into the market. Crowdfunding methods allow city dwellers to directly financially support more distant renewable energy projects whose electricity is consumed mostly by cities. The managing director of Trillion Fund, Julia Groves, has remarked that "crowdfunding has the potential to take community energy from being a hyper-local, small-scale phenomenon to something of national importance that could change the face of the energy market" (Cooke, 2014).

There are numerous examples of loan-based crowdfunding platforms for renewable energy projects, but a few are notable: Mosaic, Sun-

Funder, BetterVest, Abundance, and Trillion. Mosaic helps to fund solar installations in the US, it has raised over $8.5 million in financing and to date has generated 12 million kWh in energy (Mosaic, 2014). Abundance and Trillion finance renewable energy (RE) projects in the UK, and are a mix of wind and solar. Abundance has raised nearly £6 million to fund projects, such as the installation of solar panels on the roofs of schools around the UK, and solar panels for buildings in Nottingham (Abundance, 2014). Crowdfunding can also be used for energy efficiency projects, as demonstrated by BetterVest in Germany (BetterVest, 2014).

We have discussed in this section that, although larger financial tools are more aptly used to assist with financing energy projects at the municipal scale, the trend of decentralisation now underway means that, for future cities, an abundance of projects being developed will be smaller scale, such as households or buildings. Therefore, in order to fill all funding gaps and ensure that EE/RE projects take hold in smart cities, crowdfunding for community energy projects represents a viable and essential revenue stream.

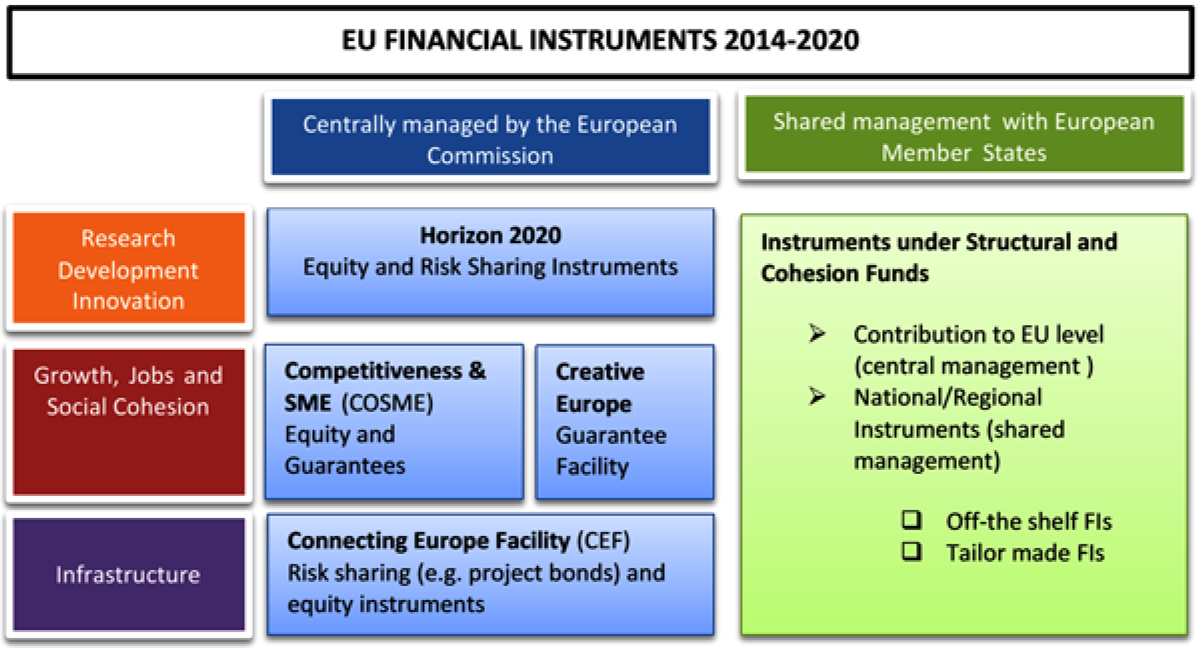
THE EUROPEAN FINANCIAL INSTRUMENTS

Smart City investments require technological initiatives and must also be sustainable in their use of public finance through which project planning and investment structuring are properly integrated. These two actions in coordination can certainly foster Smart Cities, for example, by mitigating and adapting to climate change and other energy-related challenges; moreover, they can accelerate the development and deployment of energy efficiency and low carbon technological applications, support the practice of new administrative and financial tools, and promote partnerships between the public and private sector (Finance Working Group for Smart Cities, 2014).

Within this context, in 2014 the EU has shown a clear shift in funding priorities. In the Programming Period 2007-2013 three main objectives were set out: convergence, competitiveness and employment, and European territorial cooperation. European Union investments were therefore strongly directed towards network infrastructures and the environment. The three previous objectives have been replaced in the new Programming Period, 2014-2020 by two objectives: investment for growth and job goals, and the increase of European territorial cooperation, thus addressing in the investments support for SMEs and advancement of the low carbon economy. The total allocated fund at current prices is equal to €351,9 billion (European Commission, 2014). The financial prospective for the current EU Programming Period (2014-2020) set out priorities (the 11 "thematic objectives" for the European Structural and Investment Funds) that have been designed to implement a strategically coherent use of European budgetary resources, aligned with the Europe 2020 agenda for a smart, sustainable and inclusive EU; contributing resources to the establishment of financial instruments is also highlighted. According to the European Commission, financial instruments, which are designed to use EU resources in a revolving way rather than through the traditional grant-based approach, are "a resource-efficient way of deploying Cohesion Policy resources in pursuit of the Europe 2020 strategy objectives. By targeting projects with potential financial viability, financial instruments provide support for investments via loans, guarantees, equity and other risk-bearing mechanisms (Figure 4). In light of the current economic situation and the increasing scarcity of public resources, financial instruments are expected to play an even stronger role during the Cohesion Policy in the 2014-2020 programming period" (European Commission, 2014).

The EU financial instruments can therefore offer a viable source of funding toward the advancement of smart cities; in fact, the thematic approach in the new programming period provides

Figure 4. Overview of the financial instruments in the EU programming period 2014-2020 (Source: European Commission, 2014)



the right framework for coordination and synergy. For instance, smart energy investments targeted for production, such as photovoltaic and thermal technologies, and consumption such as smart meters, must involve authorities and citizens in the design and delivery of services in order to achieve effective results. Climate challenges and the economic crisis have reinforced the need to develop strategically effective investments for urban energy and to create financial tools that are wider in scope and flexible in their application.

Prior to this drive towards a broad vision for financial instruments, the European Commission (EC) had launched JESSICA (Joint European Support for Sustainable Investment in City Areas) jointly with the European Investment Bank (EIB) and the Council of Europe Development Bank (CEB), as a technical assistance initiative designed to assist Member States in using 2007-2013 EU resources in a revolving way to promote urban development. It is worth recalling that, in the context of the shared management of EU budgetary resources, Member States need to designate so-called Managing Authorities (MAs), generally regional authorities or central government units such as Ministries, as the entities entitled to use the financial resources made available by the European Commission. Thus, the JESSICA programme assisted MAs in their efforts to use part of their Structural Fund (SF) allocations through financial instruments for urban development[1]. The SFs in question are the European Regional Development Fund (ERDF) and the European Social Fund (ESF), which together with the Cohesion Fund supported the EU Cohesion Policy through an overall EU budgetary commitment of nearly €350 bn for the 2007-2013 programming period. These funds have generally been allocated through Operational Programmes (OPs), strategic programming documents agreed between each MA, and the European Commission (EC), thus setting out investment priorities for use of the resources that have usually included both urban and energy-related objectives.

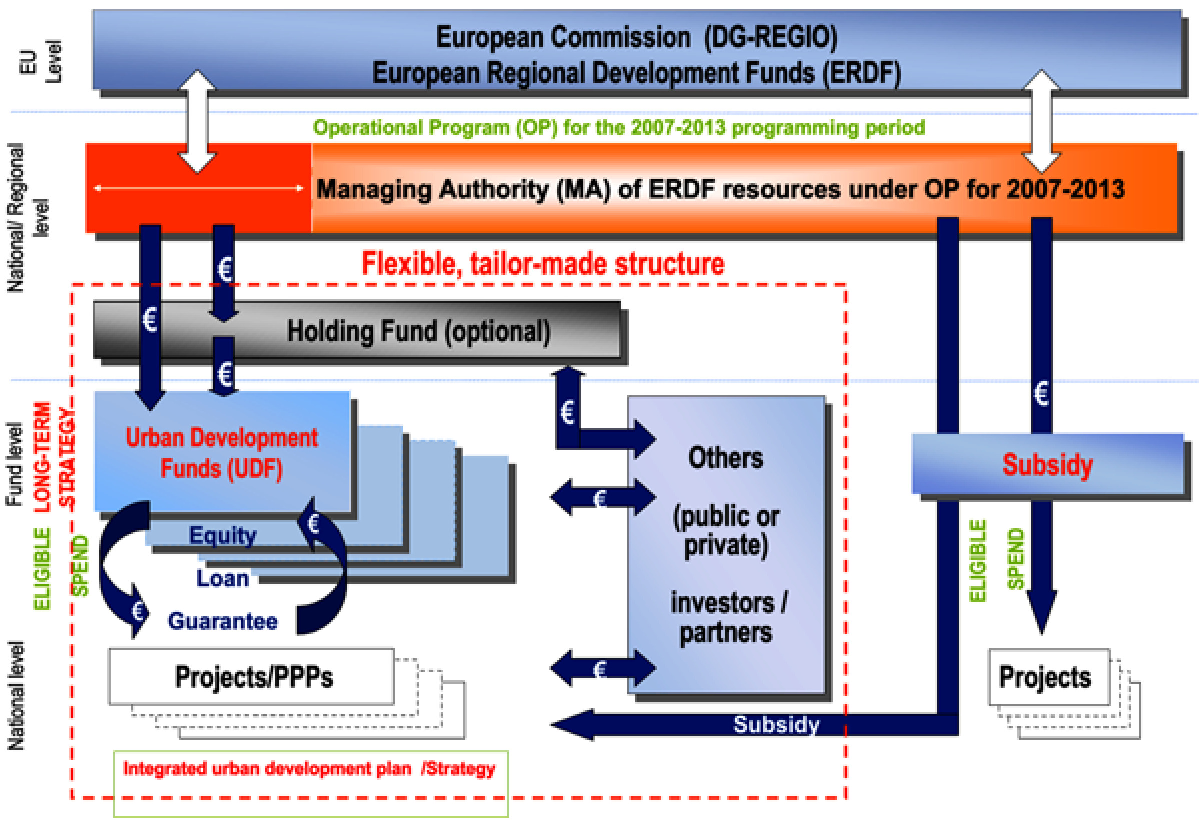
The novelty of financial instruments such as those promoted through the JESSICA Initiative – compared to the previous programming periods – is noteworthy in two ways. In the first place, they now allow MAs to employ their Operational Programme (OP) allocations through revolving instruments, which are instruments established with a view to being reconstituted through payments or other forms of remuneration after the investment is implemented, as opposed to the non-repayable grants traditionally used in OPs to fund projects. Secondly, the instruments are dedicated to 'sustainable urban development,' i.e., to fund investment capable of demonstrably achieving impacts on the sustainable transformation of cities by reaching social, economic and environmental objectives. One of the key features of the regulatory framework to enhance policy effectiveness of the instruments is the condition that they must operate within 'integrated plans.'

In places where they have been applied to urban development, these financial instruments are designated in the governing regulations as "Urban Development Funds" (UDFs) and are obliged to invest in "Public-Private Partnerships (PPPs) and other projects forming part of integrated plans for sustainable urban development" (EIB, 2013). The specific definition of integrated plans was understandably left open, given the need to accommodate 27 diverse EU Member States. However, for our purposes here, a working definition is that "(a)n integrated plan for sustainable urban development comprises a system of interlinked actions which seeks to bring about a lasting improvement in the economic, physical, social and environmental conditions of a city or an area within the city. The key to the process is 'integration', meaning that all policies, projects and proposals are considered in relation to one another. In this regard, the synergies between the elements of the plan should be such that the impact of the plan as a whole adds up to more than would be the sum of the individual parts if implemented in isolation" (EIB, 2007). It is therefore up to the MA to interpret and adapt the definition in line with local planning procedures and administrative culture. By end 2011, OP resources committed to these instruments for urban development were of the order of approximately €2 bn. The diagram in Figure 5 illustrates the main funding streams related to the establishment of UDFs within the framework of the 2007-2013 Programming Period.

While the concept of sustainable urban development is broad-based and encompasses many dimensions, in its practical implementation the UDFs – particularly in years 2010-2011 – have focused their responses towards urban regeneration on the one hand, and to urban energy and climate change objectives on the other. In the context of city energy-focused plans, the range of investment in countries such as Estonia, Lithuania, the UK, Spain, and Italy covers energy savings/ EE in buildings, to include insulation of building envelopes, heating control systems, and lighting upgrades; cogeneration (Combined Heat and Power - CHP); Renewable Energy, such as solar PVs for electricity, solar thermal, biomass, etc.; clean transport using electric vehicles, EE-driven fleet management, and biofuels.

European financial instruments for urban development in both the past and the current programming period have two salient features with regard to urban energy investments, and consequently Smart City investing. The first feature emphasises strategic and integrated approaches for the use of the funds, and the second is the requirement to identify and implement mechanisms that are able to generate returns on the investment. The first feature refers to the prioritising of smart energy investment in accordance with a systematic city approach, using diagnostics and audit procedures that cover city needs and go beyond the partial and fragmented approach often applied to RE/EE investments. The aim is to achieve a systematic plan where the investment strategy, for example through the implementation of integrated territorial investments and operations or community-led local development, is delineated over time and seen

Figure 5. Key funding streams for UDFs, 2007-2013



in the overall context of city development. Such 'seeing in the round' is critical to the assessment of medium and long-term evolution of demand for EE/RE investment and should be part of the integrated planning process[2].

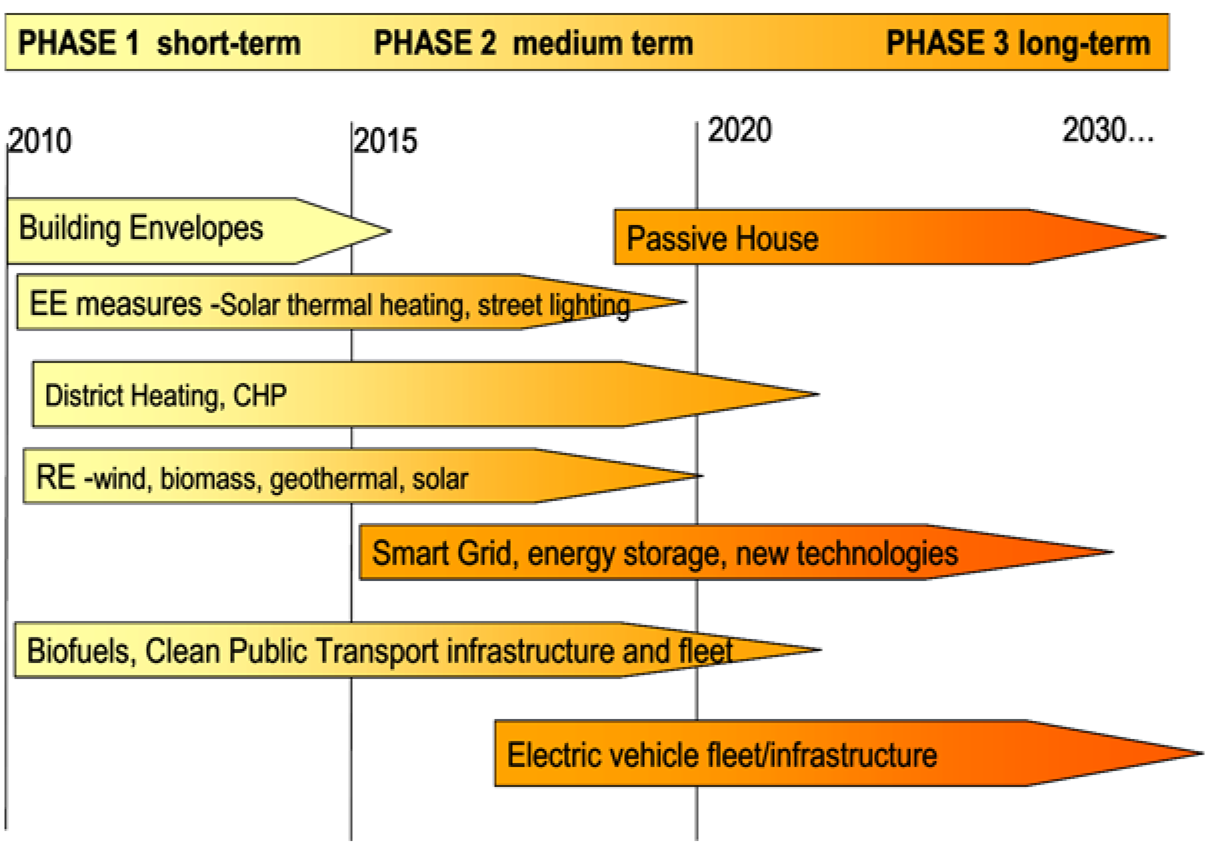
As noted above, an appropriate level of integration would encompass community strategies that reduce energy demand, improve energy efficiency, and increase resource efficiency (RE) through a systematic diagnostics of improvements in building efficiency, refurbishment, new building standards, and optimisation of technical equipment/appliances within buildings. Integration is achieved for instance, when community strategies to reduce energy demand are designed together with the installation of decentralised energy supply systems such as co-generation, heat from waste, renewables, energy storage, and more generally through system optimisation in the delivery of smart energy in urban areas.

In practice, Energy Action Plans (EAPs) or similar programming documents developed by cities can be considered as integrated plans in compliance with EU regulatory requirements. The Sustainable Energy Action Plans (SEAP) developed by many cities in the context of the Covenant of Mayors, can in some cases also represent an appropriately integrated plan. Bearing in mind that an estimated 50% of total energy is used in Europe, other closely matching documents may provide a suitable strategic background for achieving high-impact energy use and GHG emission reductions in a systematic and cost-effective way. EAPs have been introduced in various European cities through the setting of realistic quantitative targets, by formulating and implementing specific approaches, and by monitoring the results. European cities that have introduced EAPs include London, Madrid, Stockholm and Hamburg. A sound strategic approach of this type can enable the financial instruments to engage in long-term investments where projects with a shorter payback are funded first, and thereafter successive waves of investment – possibly less mature initially and/or with longer payback periods – can be funded through the reconstituted resources of the financial instruments, as illustrated in Figure 6.

Although seldom addressed in many EAPs, a second feature of European financial instruments refers to the need to find practical ways for energy-focused investments to finance the EE/RE investment and to capture financially the benefits deriving from this investment. If such value capture mechanisms can be put in place, financial instruments will be able to advantageously exploit the opportunities offered, for instance, by Energy Performance Contracting (EPCs) and Energy Service Agreements (ESAs), and which involve Energy Service Companies (ESCOs) in the investment process (See Section III). Dedicated credit lines as well as guaranteed funds or first-loss facilities can also be developed to decrease the costs and risks of the investment, particularly when the investment relates to new technologies, as often happens in Smart Cities.

In general, European financial instruments are designed to alleviate investment shortages caused by market failures or by an otherwise inadequate provision of investment for public interest objectives by unassisted market forces. This applies in

Figure 6. Illustrative phases in urban energy investing



particular to sustainable "smart" urban transformation and should be inextricably linked with the achievement of non-financial performance objectives or impacts. Put succinctly, investment by these financial instruments is meant to:

- Ensure long-term self-sustaining support for urban transformation through the use of, for example, energy smart investment through revolving mechanisms which can reconstitute the instruments thereby making them permanent support tools to be re-used for successive investment waves;
- Contribute financial and managerial expertise from specialist institutions such as the EIB, other IFIs and financial institutions;
- Leverage resources additional to those drawn from the Operational Programmes (OP), from other private and public sector sources for urban projects; and lastly to
- Create stronger incentives for successful implementation by final recipients, i.e., project implementing bodies, given the need to meet financial as well as non-financial performance objectives, i.e., remunerating investment and generating measurable public interest impacts.

An illustration of how this mechanism works in practice is provided in the next section, where the operation of a Holding Fund and the associated UDFs currently operating in the Greater London area – including their insertion into integrated plans for sustainable urban development and the specific strategic rationale underlying them – are explained in detail.

THE LONDON GREEN FUND

The structure and operational features of London's energy-focused UDFs have been established in the context of energy-focused integrated plans for sustainable development of the city. The London Green Fund is a Holding Fund managed by the EIB which has been developed on behalf of the Managing Authority – the London Development Agency (LDA) – in order to contribute to the resolution of climate change issues in addition to other sustainable urban development objectives pursued by the Mayor of London's strategy for sustainable development. Particular aims include improvement of energy efficiency in buildings, including refurbishment and optimisation of technical equipment/appliances, as well as the installation of decentralised energy supply systems, e.g. cogeneration, heat from waste, renewables, energy storage, etc., and more generally through integrated system optimisation in the delivery of energy.

The challenge for London has been to define a fund that dovetails with its sustainable urban plans in order to maximise impacts. To successfully align its goals with sustainability, the London Green Fund was tailored to implement the appropriate combination of technologies in the city to achieve energy savings and to define 'investor-friendly' financial tools that obtain cost-effective urban investment. In the London context, sustainable Energy Action Plans (EAPs) are one of the main approaches for realising cost-effective energy use and GHG emission reductions; and in this context the Mayor of London has also adopted a comprehensive Climate Change Action Plan with the aim to reduce carbon emissions by 60% by 2025 compared to 1990 levels.

The London Green Fund is a Holding fund managed by the European Investment Bank. Established in October 2009, the fund invests in carbon reduction initiatives as part of the 'London Plan,' and in total is worth £100 million:

- £50 million from the London ERDF Programme
- £32 million from the Greater London Authority (GLA)
- £18 million from the London Waste and Recycling Board (LWARB)

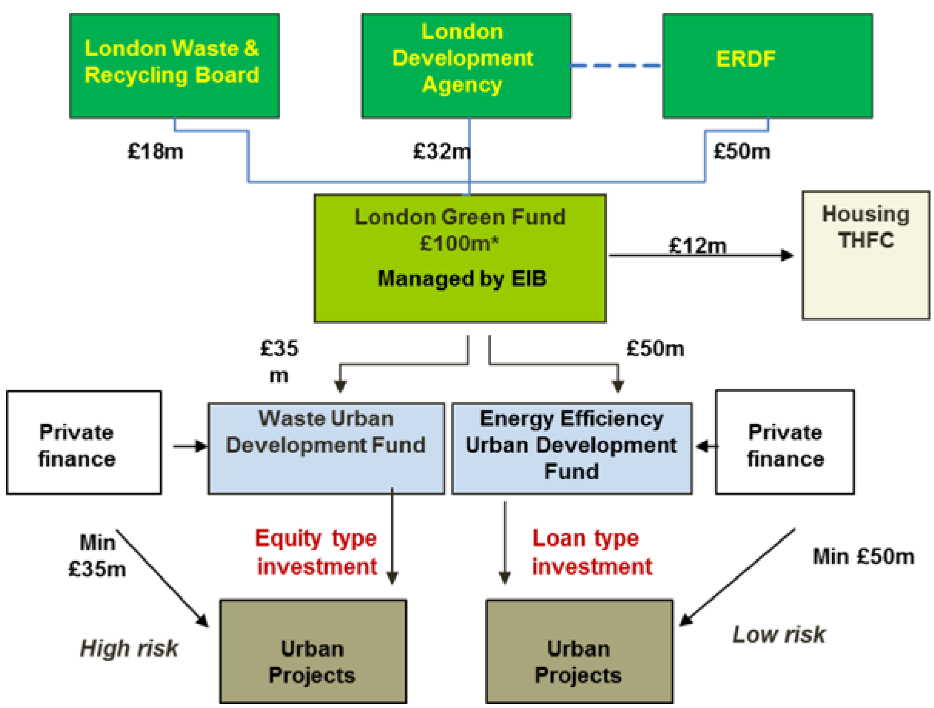
The London Green Fund provides funding to three sub-funds which are the actual energy-focused UDFs (Figure 7). The funds are targeted to the financing of London's three largest smart carbon reduction opportunities: energy efficiency, waste energy creation and decentralised energy projects.

The London Green Fund invests in projects with different risk profiles in any of London's 33 boroughs. Thirty-five million Pounds has been committed mostly via equity products to projects with a higher risk profile (e.g. waste to energy), whilst the remainder has been dedicated to lower risk projects (e.g. energy efficiency in buildings), primarily through loan-type products. The three funds are briefly described below in Figure 7.

The Foresight Environmental Fund (FEF) established in 2011, is dedicated to waste. At present, London produces 22 million tonnes of waste per year but this waste could deliver 10-20% of London's energy needs. This fund is structured to provide equity and shareholder loans to companies that build, own and operate waste urban projects. The fund manages a portfolio of up to 20 projects which will be fully deployed by December 2015. The FEF aims to fund smart projects that increase re-use and recycling and composting of waste, and also those that reduce landfill disposal. Moreover, the financed projects must minimise the amount of used energy and transport impacts arising from the collection, treatment and disposal of waste, and promote the generation of renewable energy and hydrogen from waste (Greater London Authority, 2011).

The London Energy Efficiency Fund (LEEF) focuses its resources – of which £50m are provided by the London Green Fund – on energy efficiency retrofit of mostly public sector buildings (such as hospitals, schools and public housing). In this case, building owners (public authorities) identify a portfolio of buildings they would like to retrofit. The projects eligible for the LEEF finance need to satisfy minimum performance targets, i.e. 20% carbon dioxide and 20% energy

Figure 7. Structure of the London Green Fund and the UDFs



savings, compared to the conditions prior to the investment, and for each £1,500 LEEF investment, projects should achieve a reduction of at least one tonne of CO_2. It is incumbent upon the energy service companies (ESCOs) carrying out the projects to guarantee energy saving results. By imposing this structure among the different players, "we guarantee the payback of the initial investment with the delivery risk transferred to the ESCOs. Hence, this is a cost-neutral means of reducing energy bills and carbon footprint in buildings" (EIB, 2011).

The LEEF finance considers the provision of either senior or mezzanine loans but the fund provides 100% of senior debt only for projects "if required and if appropriate security is provided" (AMBER, 2014). However, it is worth mentioning that particularly in energy saving projects the use of mezzanine financing may raise critical questions, since the instrument is often a subordinated debt which "carries a fixed coupon (between 12-14%) and an equity kicker in the form of warrants" (Arch Capital, 2007). Due to these characteristics, mezzanine debts are often considered to be an expensive form of debt. Various observers have noted that in public private partnerships, the use of higher levels of private mezzanine/subordinate debt may indeed increase the project's average cost of capital.

The Greener Social Housing UDF is the most recent (March 2013), with an allocation of £12m from the London Green Fund. The fund targets registered social housing providers to invest in the environmentally friendly refurbishment of social housing buildings.

We can observe that the three UDFs in the London Green Fund are structured with flexible financial tools in order to promote the achievement of multiple Smart City objectives such as job creation, financial remuneration, energy savings, and efficiency. But in order to implement this flexibility, the project and its specific features must lie at the core of the decision in relation to the choice of financial tools. By doing so we will obtain the best allocation of risks and financial resources in energy projects for Smart Cities.

CONCLUSION

The transition to a low carbon and climate resilient urban economy requires a paradigm shift in the energy market in order to channel significant amounts of capital from standard fuel-intensive technologies into sustainable technologies and infrastructure for smart cities. However, in order to raise the needed capital during this crucial transition period, it is not feasible to rely solely on public finance capability; the private sector must also participate in the transition to a climate resilient economy. In addressing this problem, several financial mechanisms are currently investing in energy projects designed to ensure private support of city energy agendas.

Increasingly, cities and regions interested in the use of innovative financial tools, are convinced that investment in energy efficiency (EE) and local renewable energies (RE) – with their consequent reductions of fossil fuel and CO_2 emissions – are viable tools to achieve sustainable development and improve citizens' quality of life. A focus on energy appears to be reasonable as it is fundamental to sustainable development – but also because smart energy investment is likely to have the significant potential to generate cash through RE production, and possibly more significantly, to achieve cost savings through EE investment in the urban built structure. The trend toward innovative financial tools for energy is understandably enhanced in the 'long recession,' which is still severely limiting city and regional potential to fund 'cash absorbing' investments.

We can summarise our discussion by listing the main elements that smart energy-focused finance should promote:

- Efficiency gains through integration, i.e. combining different types of investment in ways that maximise impacts on policy objectives like energy dependence/GHG reduction;
- Bridging the gap between investment with high potential benefits (energy efficiency in particular, as this does not depend on tax-supported revenue, feed-in tariffs) and funding mechanisms that do not rely on public subsidies;
- Ensuring a policy framework and support that establishes incentives and attracts private investors;
- Investors who are capable of achieving impacts while guaranteeing self-sustaining financial instruments.

In this chapter we have also examined the European context, including financial instruments as those promoted through the JESSICA Initiative that are based on the integration between strategic urban investing and self-sustaining private and public capital vehicles. The Initiative aims in essence to reduce fragmentation in urban investment programmes and increase their financial and non-financial impacts – which is certainly in line with the Smart City paradigm.

After examining the London Green Fund as an example of an energy-focused investment vehicle, we can observe that this type of fund is soundly able to instigate greater private investor participation by creating a more mature energy market where investment prospects are neither too small nor too risky to attract reliable finance. These vehicles can in principle work – together or in parallel – with other financial tools to form a financial framework that addresses the diversity of Smart City investment needs. In accordance with a project's typology and specific life-phase, one can implement different targeted funds. For instance, where projects are smaller and/or riskier, we have shown that crowdfunding can fill the gap in financing. Crowdfunding has proved to be particularly suited to community energy projects, for example, which will be critical in future in ensuring sustainable energy supply in Smart Cities.

Towards the attainment of sustainability in urban areas, we have discussed that a combination of energy-focused funds are sound financial instruments that can be tailored to individual cities in the challenge to develop integrated energy plans, and thus not only achieve energy savings and minimise GHG impacts, but do so in the most cost-effective and 'investor-friendly' ways.

REFERENCES

Abundance. (2014). Retrieved May 15, 2014, from https://www.abundancegeneration.com/

AMBER. (2014). Retrieved May 15, 2014, from http://amberenergy.net/our-story

Arch Capital. (2007). Retrieved May 15, 2014, from http://www.archcapgroup.com/

ARUP. (2011). *Analysis of renewable energy to inform UK investment*. Retrieved May 15, 2014, from http://www.arup.com/News/2011_06_June/10_Jun_11_DECC_Analysis_of_Renewable_Energy

BASE. (2006). *Public finance mechanisms to increase investment in energy efficiency. A report for policy makers and public finance agencies*. Retrieved May 15, 2014, from http://www.energy-base.org/wp-content/uploads/2013/11/SEFI-Public-Finance-Mechanisms-to-Increase-Investment-in-Energy-Efficiency.pdf

Bertoldi, P., Boza-Kiss, B., & Rezessy, S. (2007). *Latest development of energy service companies across Europe*. Retrieved from http://www.energy.eu/publications/LBNA22927ENC_002.pdf

Bertoldi, P., Rezessy, S., & Vine, E. (2006). Energy service companies in European countries: Current status and a strategy to foster their development. *Energy Policy*, *34*(14), 1818–1832. doi:10.1016/j.enpol.2005.01.010

BetterVest. (2014). Retrieved May 15, 2014, from http://bettervest.de/

Capital, R. A. B. (2011). Retrieved from http://www.rabcap.com/home/?btnDisc1=Accept&pageLocation=cpi_a_rab

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart Cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. doi:10.1080/10630732.2011.601117

Cooke, R. (2014). *Crowdfunding is a financial lifeline for community energy*. Retrieved May 15, 2014, from http://trillionfund.com/crowdfunding-is-a-financial-lifeline-for-community-energy/

Croce, R. D. (2011). *Pension Funds Investment in Infrastructure: Policy Actions*. Working Papers on Finance, Insurance and Private Pensions 13. Paris, France: OECD Publishing.

Deakin, M., & Allwinkle, S. (2007). Urban Regeneration and Sustainable Communities: The Role of Networks, Innovation, and Creativity in Building Successful Partnerships. *Journal of Urban Technology*, *14*(1), 77–91. doi:10.1080/10630730701260118

DECC. (2014). *DECC Statistics: Renewable Energy Trends*. Retrieved from https://www.gov.uk/government/publications/energy-trends-section-6-renewables

Ellabban, O., Haitham, A.-R., & Frede, B. (n.d.). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable & Sustainable Energy Reviews*, *39*, 748–764.

Energy Charter Secretariat. (2003). *Third party financing: Achieving its potential*. Retrieved from http://www.encharter.org/index.php?id=172&L=0

Energy Efficiency Financial Institution Group. (2014). Retrieved from http://www.endsreport.com/43517/european-commission-energy-efficiency-financial-institutions-group-report-on-how-to-drive-new-finance-for-energy-efficiency-investments

European Commission. (2013). Renewable Energy Progress Report. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0175&from=EN European Commission. (2014). *Financial Instruments in Cohesion Policy 2014-2020*. Retrieved from http://ec.europa.eu/regional_policy/thefunds/funding/index_en.cfm

European Investment Bank. (2007). *Investment Facility. EIB, Luxembourg European Investment Bank. (2011). The ELENA Facility. EIB, Luxembourg European Investment Bank. (2013). Review of the European PPP Market*. Luxembourg: EPEC.

European Parliament. (2006). Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services. Official Journal of the European Union, 64-85.

European Renewable Energy Council. (2014). Retrieved from http://www.erec.org/

Eurostat. (2014a). *Eurostat - nrg_100a: Supply, transformation, consumption - all products annual data*. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en

Eurostat. (2014b). *Eurostat - nrg_ind_335a - Share of energy from renewable sources*. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_335a&lang=en

Finance Working Group for Smart Cities. (2014). Retrieved from http://eu-smartcities.eu/groups

Fusaro, P., & Vasey, G. (2006). *Energy And Environmental Hedge Funds: The New Investment Paradigm*. New Jersey: Wiley Finance.

Greater London Authority. (2011). *The London Plan: Spatial development strategy for Greater London*. London: GLA.

Heeter, J., & Mclaren, J. (2012). *Innovations in Voluntary Renewable Energy Procurement: Methods for Expanding Access and Lowering Cost for Communities, Governments, and Businesses Acknowledgments*. Retrieved from http://renewablemarketers.org/pdf/NREL_2012_innovation.pdf

Hopper, N., Goldman, C., Gilligan, D., Singer, T., & Birr, D. (2007). *A Survey of the U.S. ESCO Industry: Market Growth and Development from 2000 to 2006*. Retrieved from http://escholarship.org/uc/item/7wr0d765.pdf

Hvelplund, F., Möller, B., & Sperling, K. (2013). Local ownership, smart energy systems and better wind power economy. *Energy Strategy Reviews*, *1*(3), 164–170. doi:10.1016/j.esr.2013.02.001

International Energy Agency. (2013). *World Energy Outlook: Redrawing the Energy Climate Map*. IEA, Paris Institute for Energy and Transport. (2003). *ESCO Financing Options*. Retrieved from http://iet.jrc.ec.europa.eu/energyefficiency/european-energy-service-companies/financing-options

Julian, C., & Olliver, R. (2014). *Community Energy: Unlocking Finance and Investment – The Way Ahead*. Retrieved from http://www.respublica.org.uk/documents/lfv_Community Energy - Unlocking Finance and Investment - The Way Ahead - UPDATED DESIGN.pdf

KfW. (2011). *Annual Report*. KfW Bankengruppe. Retrieved from https://www.kfw.de/Download-Center/Finanzpublikationen/Financial-publications-PDFs/1_Geschäftsberichte-E/Geschäftsbericht_2011_E.pdf

Larsen, P. H., Goldman, C. A., & Satchwell, A. (2012). Evolution of the U.S. energy service company industry: Market size and project performance from 1990–2008. *Energy Policy*, *50*, 802–820. doi:10.1016/j.enpol.2012.08.035

Manville, C., ... (2014). *Mapping Smart Cities in the EU*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

Marino, A., Bertoldi, P., Rezessy, S., & Boza-Kiss, B. (2011). A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. *Energy Policy*, *39*(10), 6190–6198. doi:10.1016/j.enpol.2011.07.019

Mitchell, W. (2007). *Intelligent cities*. Retrieved from http://www.uoc.edu/uocpapers/5/dt/eng/mitchell.pdf

Mosaic. (2014). Retrieved May 15, 2014, from https://joinmosaic.com/

OECD. (2011). *Green Energy Studies: Energy*. Paris, France: OECD Publishing.

Okay, N., & Akman, U. (2010). Analysis of ESCO activities using country indicators. *Renewable & Sustainable Energy Reviews*, *14*(9), 2760–2771. doi:10.1016/j.rser.2010.07.013

Pew Charitable Trusts. (2014). *Who's winning the clean energy race?* Retrieved from http://www.pewtrusts.org/~/media/Assets/2014/04/01/clenwhoswinningthecleanenergyrace2013pdf.pdf

Poole, A., & Stoner, T. (2003). *Alternative Financing Models for Energy Efficiency Performance Contracting*. The USAID Brazilian Clean and Efficient Energy program. Retrieved from http://www.inee.org.br/down_loads/escos/Alternative Financial Models for EPC.doc

Rossi, M. (2014). The New Ways to Raise Capital: An Exploratory Study of Crowdfunding. *International Journal of Financial Research*, *5*(2), 8–18. doi:10.5430/ijfr.v5n2p8

Satchwell, A. (2010). *A Survey of the US ESCO Industry: Market Growth and Development from 2008 to 2011*. Retrieved from http://escholarship.org/uc/item/2114b1bx

Sclafani, A. (2008). The Role of Energy Service Companies in Accelerating Solar Technology To Market. *Strategic Planning for Energy and the Environment*, *28*(2), 24–35. doi:10.1080/10485230809509191

Siemens. (2009). *European Green City Index*. Retrieved from http://www.thecrystal.org/assets/download/European-Green-City-Index.pdf

Toke, D. (2005). Community wind power in Europe and in the UK. *Multi Science Publishing Journal on Wind Engineering*, *29*(3), 301–308.

Vine, E. (2005). An international survey of the energy service company (ESCO) industry. *Energy Policy*, *33*(5), 691–704. doi:10.1016/j.enpol.2003.09.014

KEY TERMS AND DEFINITIONS

Community Energy Projects: Are projects that are built through local engagement and collectivism, where the community benefits from energy and revenues generated by the projects. These projects involve collective action to reduce energy consumption and encourage decentralised generation of energy, often with the aims of decarbonising local economies and democratising energy governance.

Energy Action Plans (EAPs): Are documents where a national or local entity sets out energy targets and explains the mix of technologies they plan to use along with any measures they will undertake in order to overcome encourage the development of renewable energy.

Energy Efficiency (EE): Is a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input. This can be accomplished through many means, including renovating building stock to improve insulation and installation of more efficient lighting, heating, and cooling systems. The end objective is decreased energy consumption. Both of these terms are included in the concept of Smart Energy, which encompasses RE/EE along efficient distribution via Smart Grids and optimised consumption with smart metering and energy storage.

Energy Performance Contract (EPC): The UK Energy Efficiency (Encouragement, Assessment and Information) Regulations act of 2014 gives the meaning of “energy performance contract” as “a contract under which energy efficiency measures are: a) provided; b) verified and monitored during the whole term of the contract; and c) paid for by reference to a contractually agreed level of energy efficiency improvement or other agreed criterion such as financial savings.” https://www.gov.uk/government/publications/energy-performance-contract-epc

ESCO: An energy service company or energy savings company is a commercial or non-profit service provider that facilitates a wide range of energy savings projects, including retrofitting, energy conservation, power generation, and risk management, usually by Energy Performance Contracting (see below). Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on Energy End-use Efficiency and Energy Services (Energy Services Directive) defines an ESCO as "a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria."

Integrated Planning: An approach to urban planning aimed at designing a sustainable and socially cohesive urban environment, which takes into account the linkages between a broad range of variables and stakeholders in order to achieve an optimal and community-shared outcome.

JESSICA (Joint European Support for Sustainable Investment in City Areas): Is a range of financial tools that are used including equity investments, loans, and guarantees that offer new opportunities for the use of EU Structural Funds. Investments are delivered to projects via urban development funds or holding funds, and must be in accordance with Structural Fund operational programmes agreed for the current programming period. JESSICA is a policy initiative of the European Commission (EC), developed jointly with the EIB and in collaboration with the Council of Europe Development Bank (CEB). http://www.eib.org/products/blending/jessica/index.htm

Renewable Energy (RE): Comes from "resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat." These sources of energy are inherently low-carbon.

Smart Cities: Are the cities that use embedded digital technology to enhance quality of life and foster sustainable economic growth through improved management of resources and participatory governance. The term "smart" stems from enhanced IT systems which can be applied to energy, transport, water, waste, and other aspects of urban infrastructure.

Structural Funds: "The Structural Funds and the Cohesion Fund are the financial instruments of European Union (EU) regional policy, which is intended to narrow the development disparities among regions and Member States. The Funds participate fully, therefore, in pursuing the goal of economic, social and territorial cohesion. There are two Structural Funds: the European Regional Development Fund (ERDF) and the European Social Fund (ESF)." http://europa.eu/legislation_summaries/glossary/structural_cohesion_fund_en.htm

Sustainable Energy Action Plans (SEAP): Developed by many cities in the context of the Covenant of Mayors, are "the key document in which the Covenant signatory outlines how it intends to reach its CO_2 reduction target by 2020. It defines the activities and measures set up to achieve the targets, together with time frames and assigned responsibilities." http://www.covenantofmayors.eu/+-Sustainable-Energy-Action-Plans,50-+.html.

Urban Development Fund (UDF): An Urban Development Fund (UDF) invests in public-private partnerships and other projects included in an integrated plan for sustainable urban development. A UDF can be a separate legal entity or be established as a "separate block of finance" within an existing financial institution. UDFs can be established at either a national, regional or local/city level in response to integrated urban development plans, project pipelines and investor interests." http://www.eib.org/products/blending/jessica/funds/index.htm.

ENDNOTES

1 The procedures are set out formally in Council Regulation (EC) 1083/2006, Regulation EC 1080/2006 and Commission Regulation 1828/2006 and their successive amendments.

2 It should be noted, however, that although the strategic approach remains a key general requirement in the 2014-2020 programming period, the specific 2007-2013 regulatory requirement: that projects financed by a UDF must be "part of an integrated plan for sustainable urban development," is no longer applicable. There is now greater flexibility in designing how an effective urban or territorial investment strategy for a financial instrument can be implemented.

Chapter 20
Attaining Sustainable, Smart Investment:
The Smart City as a Place-Based Capital Allocation Instrument

Eugenio Leanza
European Investment Bank, Luxembourg

Gianni Carbonaro
European Investment Bank, Luxembourg

ABSTRACT

This paper presents a research agenda focusing on the role of smart, socially inclusive, sustainable cities in furthering the balanced, equitable development of the European economy. In order for cities to play this role it is necessary to start from a vision of the city as a system of interlinked assets, and from the need to manage these assets in a sustainable way using a methodology broadly based on the principles of corporate finance. This research agenda aims to span areas of expertise and policy dimensions that are often fragmented, in order to lead to improved diagnostics and strategic investing. In Europe, this vision of the city and of the urban management process will enable better bottom-up policy delivery, and address the challenges facing the European economy by facilitating the adaptation of European city systems to diverging spatial growth patterns, youth unemployment, ageing populations, migration patterns, and increasingly sharp financial divergences among different territorial systems.

INTRODUCTION

Cities and the urbanisation process are increasingly seen as key drivers of global development (see Glaeser, 2011, Glaeser, 2008 & Dobbs et al., 2011). According to recent estimates, the urbanised share of the world's population could reach five billion people (60%) by 2030, compared with 750 million (29%) in 1950 (see Véron, 2006). This dramatic increase, and the manner in which it is coming about - mainly through rapid migration from the countryside towards the fringes of established cities in fast-rising emerging economies (see Saunders, 2010 & Davies, 2006) – not only has

DOI: 10.4018/978-1-4666-8282-5.ch020

very strong implications for the macro-economy and the social system, but will also have a long-lasting environmental impact. According to the European Commission, since the mid-1950s the land area occupied by cities in the EU has increased by 78%, even though population has grown by only 33%. Land taking and soil sealing partly decoupled from population growth, an even faster growth in fixed capital assets, and the general lack of integrated planning, have serious negative effects on food production, water resources, climate resilience and environmental protection. Urban researchers, planners, city managers and technology specialists will need to become aware of the importance of smart city investment in a world of globalised markets, and as we shall see, of the growing impact of finance in shaping urban and territorial dynamics.

Challenges to Smart City Investment

Why is investing in smart, socially inclusive and sustainable cities an issue? What barriers exist to such investment? Which funding or implementation gaps need to be addressed? An initial, simplistic reaction is to blame the "great recession" and the lack of money to fill the "funding gap". Others could object that the municipal infrastructure industry, real estate and financial sector have tried to spur urban growth at all costs in the decades leading up to the recession, following top-down, short-sighted and socially inconsistent approaches, and that the *polis* has become more a field for political in-fighting than an area for effective cooperation among social groups, with neo-liberal urban development strategies at the roots of growing social imbalances (Harvey, 2012 & 2010). In our view there are three factors which hinder the advancement of smart city investment: a) the lack of an analysis of the financial roots of the current global spatial transformation, which has led to the rapidly increasing movement of production, services, financial resources and workers across countries and cities within a context of rapidly falling transport and production costs; b) a limited understanding of the ways in which financial imbalances impact the long-term spatial economic mechanisms leading cities to thrive or decline – and possibly default on their financial obligations; c) the limited availability, with the possible exception of niche courses in more sophisticated countries, of higher education institutions providing specialist know-how about innovative/holistic models for sustainable city management, strategic investment and urban governance. Urban studies remain prevalently focused on technical and sector-driven approaches, while links between urban development and the macro-economy, monetary policy and demographics remain relatively unexplored.

Overcoming Barriers: New Roles for Mayors and Citizens?

Even successful cities may have large pockets of deprivation and under-development. Despite the creative classes, "triumphant" cities and the many success stories we hear, many cities do not just suffer from poor resilience to climate change or sub-optimal ICT infrastructure, as mayors are confronted daily with acute social problems involving young people, elderly citizens, immigrants and at-risk households, and the challenges of unemployment, affordable housing, education standards, long-term care and so on. Growing competitive pressures and rapid technological change impinge on city management, with many cities facing increasingly severe reductions in tax revenue and the drying up of fiscal transfers. These conditions affect the administrators' capacity to look for long-term strategies, as decision making is often hampered by previous deliberations, obsolete planning, new regulations, non-functioning bodies, management turn-over and a lack of know-how and of urban integration professionals. Without the support and energies of their citizens, it is hard for city reformers to design and implement smart, sustainable urban transformation, especially considering the lack of the ready-to-use strategic information systems required to support investment decisions.

Why is smart innovation often so difficult, and in some cases politically controversial? Firstly, smart city investment, as with any type of capital expenditure, should have returns and pay-backs compatible with economic agents' expectations and cost of capital. Despite the vast potential to augment citizens' human capital, this equation is endangered by the vulnerability of current wealth to disruptive technological change, which may render a wide range of current material and immaterial assets[1] obsolete or redundant. Secondly, the technology involved often has a short life and may be expensive and potentially risky, due to its complexity and vulnerability to cyber-attacks or accidents. Thirdly, economic advantages or savings for users and the citizenry are not always obvious. Patent-protected innovations are imported into the city creating the risk of supplier dependency, contributing marginally to local employment and economic empowerment while expanding the areas of rent to the detriment of the labour factor. Some resistance towards the introduction of new technologies is foreseeable from incumbents who have built up substantial rent positions over time e.g. local administration, banks and traditional technology suppliers. Finally, often resource-strapped cities do not have the necessary skills to prepare investment plans and capital expenditure budgets that can be funded through operating cash-flows associated with the investment. Despite the role of planning and top-down decisions in shaping urban development, cities are fundamentally market creations resulting from decentralised bottom-up locational and investment decisions taken by households and entrepreneurs who normally reap the advantages deriving from consumer choices and entrepreneurial, risk-taking decisions. In urban growth cycles, the citizens' gains in this process are reinvested in successive waves of urban capital expenditure and innovative technologies, as are the skills and entrepreneurial spirit of the immigrants. Successful cities grow by stratification, perpetuating over time the agglomeration economies that preserve their wealth and their residents' utility[2]. In cities, the bulk of capital investment and maintenance is carried out by the private sector - individuals, households, enterprises and not-for-profit operators. In parallel, traditionally the public sector has played a preponderant role with regard to the majority of infrastructures and collective assets, influencing development through planning regimes and regulations, sector-specific policies (e.g. limits to municipal borrowing, building codes, local taxation, etc.), and fiscal subsidies and other transfers.

Due to the size of their infrastructure and mismatch between upfront capital expenditure and long financial pay-backs, cities and urban investors have increasingly substantial recourse to credit in different forms and scope. Often city residents, including the immigrants guaranteeing the cities' demographic regeneration, do not possess the means to satisfy their residential needs without external financial support, including social housing that provides accommodation at below market rates. City development has become largely dependent upon the availability of finance in various technical forms, in which money is on-lent to increasingly leveraged municipalities and urban stakeholders. In this context, monetary policy and its transmission affect urban transformation paths through the availability and cost of credit. The role played by tax regimes and other fiscal benefits favouring capital accumulation, is particularly important. Tax regulations in particular provide a wide range of tax shields, incentives for deductions on capital expenditures and other charges on physical assets, support for private home ownership and the permitted netting of financial charges or capital losses incurred in real estate investment. The regulatory environment in which urban capital allocation and borrowing decisions are taken is thus in many ways a "policy artefact", and this artificiality impinges upon the form and timing of urban capital accumulation.

Naturally this should also be seen against the wider backdrop of macroeconomic imbalances brought about by the combination of the "long recession" and loose monetary policies, such as the vicious circle between mounting public debt and the growing share of public securities in the banks' balance sheets, which increases the overall vulnerability of national banking systems to sovereign debt crises[3].

FINANCE AND CITIES

Cities and Monetary Policy Channels

Physical investment – of which city assets constitute a central component – has traditionally been considered a key channel for the transmission of monetary policy (Mishkin, 2001 & 2007; Milcheva & Sebastian, 2010; McCarthy & Peach, 2002). From Bretton Woods onwards, it has been specifically targeted by national and monetary authorities in order to foster, or counter-cyclically stabilise, growth and employment in western economies. Baby-boomers' demand for residential assets was steady, strong and easily predictable[4], enabling a monetary approach based on the expansion or reduction of credit for, among other things, property investment. So the growth of metropolitan areas was often supported via large-scale planning-led "Fordian-Keynesian" infrastructural projects often located on the edges of cities, in their suburbs or their satellite districts (see Garreau, 1991). A further distinctive aspect of residential investment and the long-term growth of residential property prices, was their impact on households' wealth which has countered the high concentration of financial wealth. The wealth effect of residential ownership has also been used by the Federal Reserve and other central banks, among other things to sustain, somewhat artificially, consumption levels and aggregated demand (European Central Bank, 2009). Likewise, according to various observers the relevance of the traditional European city model featuring the central economic and symbolic role played by the historical cores, has progressively faded[5], to be replaced by the "American City" and the "Asian City", characterised by different rationales and structures. In many countries, increasing land prices, the growing role of private transport and social imbalances in central cities, have gradually led towards the development of polycentric metropolitan regions, which flatten land rent profiles through peri-urban growth, and make housing costs more affordable.

The debate among central bankers, economists and financial specialists has evolved lately, as various property market bubbles – including the "post-Lehman" crisis originally triggered by a shock in sub-prime and mortgage-ABSs – have threatened the economic and financial stability of the industrialised economies. Although this debate is generally not centred on cities, many observers are aware that the majority of the financial crises hitting advanced countries since the 1970s have – like the 1929 depression – a critical domestic real-estate component[6]. The recent past has been characterised by the unconventional monetary policies adopted by the major central banks (in Japan, then in the USA, Canada, the UK and, to a lesser extent, the Euro area), involving the expansion of the monetary base and the purchase of banking assets to stabilise the financial markets and stimulate economic recovery. These policies were considered necessary to counter rapid banking deleveraging in the credit sector and the withdrawal of credit resources from the real economy. These policies have also been heavily criticised due to the implicit massive transfer of wealth from society towards the financial sector (Stiglitz, 2012b). In the western economies, the past five years have been characterised by poor aggregated demand and the slower growth of credit aggregates compared to the growth of the monetary base, with a divergence between a subdued "Main Street" and an exuberant Wall Street (stock exchanges and financial markets). Meanwhile, low interest rates have encouraged the search for high yields, and large amounts of capital have been moved out of western economies. The central banks' quantitative easing has finally led to an acceleration of urban activity and property prices in growing urban poles (e.g. in the UK and Germany), and to a larger extent in emerging market economies, especially in Asia. However, urban demand has continued to remain flat in many locations (Zhu, 2005). High volatility in emerging markets was ignited when the Federal Reserve hinted at tapering off its monetary policy in the second quarter of 2013 and, more aggressively, in January 2014. This reaction shows how global financial markets – and urban property markets – are now so closely interconnected that central banks' activities induce large spill-over effects in other economies. This indicates that there is a much stronger link between the monetary policy of the Federal Reserve and other central banks on the one hand, and capital flows into emerging export-driven economies and global urbanisation on the other. Monetary policy decisions are thus not "spatially neutral", as they accelerate the pace of physical capital expenditure across the world and exacerbate the divergence between different territories (Mohan & Kapur, 2014; Eichengreen, 2014 & 2013). This emphasis on the role of monetary policy should not lead to any underestimation of the impact of the increasingly unequal distribution of income and wealth on the sharp, spatially-diversified movements of asset prices, including city assets. The disruptive impact of inequality on growth has been noted by several authors (Rajan, 2010; Piketty, 2013), and in this context the design of city management and investment strategies should strive to address the discrepancy between investment priorities determined by loose monetary policies and heavily asymmetric income and wealth distribution, and those desirable for the balanced, equitable development of cities.

A Leading Role for Customised Smart City Strategies

The effects of the unwinding of the unconventional monetary policy stance in a context of globalization and an ageing population, may well challenge some of the traditional assumptions regarding the effects of monetary policies, e.g. the mechanism of credit transmission or the shape of the inflation/employment trade-off[7]. Some of the effects on countries, regions and cities will be unexpectedly sharper than in the past. In this context, there are strong reasons for introducing "smart city" strategies and technologies as innovative instruments designed to direct capital allocation in cities, leading to a more sustainable and selective use of scarce economic resources in favour of productive investment and job growth. From an economic perspective, the smart city agenda would help authorities and other urban stakeholders to target investment, to allow a leaner, more transparent management of urban assets in line with the expected returns and costs. From our point of view this should be connected to the reinforcement of the revenue capacity of urban workers, entrepreneurs and "prosumers" (together constituting the "human capital" factor) and to the prospective growth of city's wealth. A job-led approach would also enhance cities' economic resilience, long-term sustainability and competitiveness[8].

Globalisation enhances the economic importance and – up to a point – the autonomy of territorial and urban systems vis-à-vis nation-states.[9]A few powerful cities[10] enjoying governance capacity and able to take advantage of unique agglomeration economies, can gain relative economic dominance vis-à-vis nation states and other urban competitors, although the scale factor alone is not a guarantee of success, and in some cases determines higher systemic risk (Sassen, 2001 & 2002). Globalisation has accelerated urban growth in the dominating centres, while at the same time giving prominence to high-productivity, "cashgenerative" metropolitan economies[11] in which the goods/service "export" capacity and the ability to attract investment and financial transfers, determines global success. However, when analysing smart city implementation strategies, we are faced with three different models. First, there is a limited number of expanding, internationally-open urban systems with high growth elasticity to globalisation, such as London, New York, Tokyo, Hamburg, Amsterdam, Toronto, Sydney, Hong-Kong and Singapore. These are the prime natural targets for the industry-led smart city solutions. Secondly, there are the "adaptive" city systems, in practice the large majority of urban areas, characterised by an overall neutral or negative elasticity to globalisation. These cities often experience a decline in competitiveness, a stagnating or shrinking local economy, and employment problems, often related to the movement of manufacturing capacity towards low labour-cost countries, and the loss of skilled human capital. Thirdly, there are several so-called "megacities", mostly located in emerging economies; these are large metropolitan areas which, despite rapid demographic growth, do not achieve a similar degree of progress in terms of economic performance and institutional capability, thus representing a potential source of concern in terms of their social, environmental and financial stability.

Smart city development cannot be implemented in isolation, but should be linked to a national agenda that is aware of the need for a place-based investment strategy, of the challenges confronting cities – energy, ageing population, mobility – and their financial implications. A further key element – as we shall see later on – is the presence of policy-driven financial vehicles capable of selecting and financing strategic urban projects. With the support and guidance of a city management office, a concerted effort in this direction could act as a catalyst for integrated and job-creative investments by a number of urban stakeholders. In order to facilitate the establishment of the necessary decisional support system, this approach is likely to involve the opening/sharing of the key data systems providing integrated multi-sector place-based strategies through innovative forms of cooperation between national, regional and urban authorities and the private sector. The availability of correct place-based information is a pre-requisite for the maximization of the economic or employment impact of investment in relation to capital allocation decisions of a complex nature. In cities having to deal with the effects of asset bubbles, economic shrinkage, liquidity crises and asymmetric shocks affecting local labour markets, a "smart" capital allocation tool would provide public decision-makers with the rigorous analysis and discipline necessary to implement turn-around strategies that are more likely to succeed[12].

The Limits of Municipal Finance and the Need for Specialised Vehicles for Transformative Investment

Due to the lack of strategic alignment and coherence between banks' corporate objectives and a city's multi-purpose mission, the success of smart investment strategies will often depend upon the existence of specialised financing vehicles, transparently governed and professionally managed with a clear vision of the city's long-term transformation objectives. The operation of these institutions should be aligned to the impact fund paradigm which has been developed to a considerable extent over the past decade, although the market-driven approach often proposed by the impact fund industry may have a limited ability to address the risks of urban capital misallocation (Posen, 2003). Experience shows that market players are often excessively focused on short-term indicators, and lack the technical expertise to structure and implement place-based investments crucial to infrastructural projects.[13] Hence the need to look at institutional innovation, in the form of municipal financing vehicles providing a combination of the technical know-how and specialist expertise required to direct the city towards sustainable and financially stable development. The creation of a dedicated "smart" financing vehicle would facilitate the supporting investments that are critical for urban transformation and that are unlikely to be financed by globalised banks increasingly removed from the experience and developmental role of the former savings banks.

Transformative urban investment creates the scope for institutional and social innovation, as few metropolitan areas can be considered to be following a well-established, smart, socially inclusive, sustainable development path already. It has been recently observed how critical institutions are in determining economic performance, particularly in a globalising world economy (Acemoglu & Robinson, 2012). Thus, a solid, transparent institutional framework that is resilient to the penetration of corruption and crime, is a key component to the design and implementation of transformative smart investing – and certain countries, regions and cities are likely to perform better than others also in view of the attention paid to social inclusiveness and other ethical factors. In this context, innovative city funding, perhaps combining top-down and bottom-up approaches, could also alleviate the negative implications of unequal wealth distribution by allowing citizens to play an active role in investment choices.

To this effect, a suitably empowered unit – headed by a Chief Sustainability Manager or Information Officer – could monitor the city's energy and environmental services and resource flows, linking them to planning decisions and the management of other city assets and job impacts, in order to draw implications for the sustainable development of overall urban wealth[14]. Smart technology and open data could provide critical information on city assets, including infrastructure peak use, resource flexibility, municipal service availability, asset resilience and planned expansions. A Chief Sustainability Office well integrated within the city administration could contribute to the twin strategic objectives of sustainable development and financial resilience, anticipating real estate bubbles, ensuring housing affordability and reinforcing local employment prospects. In the Eurozone countries, the analytical skills and micro territorial data sources of the former central banks could also be used to provide critical data, know-how and technical advice.

TOWARDS A NEW URBAN METRICS

Enhancing the Performance of Cities as Functional Economic Areas and Dense Job Systems

According to the OECD (2013, 2009), metropolitan/urban areas should be considered as functional economic entities, characterised by high job density and the functional interdependence of social and economic activities within the area. In these territories, the performance of material and immaterial assets is deeply interdependent: human capital is linked to natural capital, fixed productive capital (housing, means of production, logistics and infrastructures), financial capital and spatial capital (i.e. location-specific factors)[15]. In mature economies, the present net value of the job system is, to a large extent, the most important component of a city's wealth and cash-generating capacity. This implies that in shrinking urban systems, the key strategic objective should be the preservation of the earning capacity of existing and future city residents, i.e. the integral of their expected revenue streams, while economic rationalisation should aim at reducing inefficiencies and lowering fixed costs in order to preserve urban competitiveness. It is important to assess the share of productivity increases likely to be capitalised into land and property values that can be taken advantage of by city operators, as this can constitute a local source of independent funding for future investment. Where possible, the administrative boundaries of the functional urban area should be defined so as to facilitate this type of value capture and to exploit synergies between the increased earning capacity resulting from human capital policies on the one hand, and the positive long-term dynamics of land and property values on the other[16].

Globalisation and innovation generate growing competition between different places, and increased volatility in the geography of economic performance, which should be addressed by rethinking the role of "place-based" or "place-aware" strategies (Moretti, 2012; Neumark & Simpson, 2014). In this context, the use of a "corporate finance" approach represents a powerful tool with which to analyse urban economies and their performance in terms of value creation and cash generation capacity – the key factor being that in order to guide "smart" investment decisions, a city or urban system needs to be treated as a corporate entity. The performance of individual projects, small and larger companies and the working population as a whole, is increasingly influenced by the competitive structure and financial conditions of the urban systems in which they operate (Moretti, 2012). Slow post-2008 growth and the ageing process[17] exert increasing pressure on the performance and investment capacity of many cities.The emergence of location-specific risk factors, and the increasingly limited scope for fiscal transfers by central governments, mean that more attention needs to be paid to geographical factors, location-specific risk measurement and provisioning, as well as to a potentially wider role for local, bottom-up policies, as central monetary support can only provide temporary relief as such.

Strategic Investment in Cities and the Need to Overcome Fragmentation

A multiplicity of players interact in urban systems, their behaviour often driven by un-coordinated decision-making. Individually they aim to maximise the return from their decisions, a goal which can be achieved through core revenue streams (e.g. improved earning capacity via better education) or speculative gains (e.g. an increase in the value of real estate holdings). Urban agents generally hold more than one of the aforementioned five types of capital, and are affected in different ways by policy decisions (such as taxation). In this context, the adoption of a consolidated[18] corporate finance approach is motivated by the need to improve the measurement of the long-term economic performance of capital allocation decisions, as assessments based on more conventional GDP-type metrics may misjudge the capacity of urban systems to maintain their financial stability and regenerate their wealth[19]. Mainly as a result of the practical difficulties of establishing a correct accounting framework, and of limited data availability, to date there has been very little, if any, experience of drawing up "consolidated accounts" for cities, as a basis on which to calculate ROI/ROA indicators and compare them with the cost of capital and with indicators of long-term organic economic performance. However, the drafting of pro-forma "place-based" financial statements representing the above-mentioned five types of capital, and the accurate collection of critical economic and financial data (including relevant tax-revenue or social security transfers) is a necessary step towards supporting strategic investors with correct territorial diagnostics and future vulnerability scenarios.

Urban leaders' political inclination to satisfy voters' peak demand for services and infrastructures, naturally generates a tendency towards over-spending. This could be mitigated by ensuring the significant financial participation of citizens and users in the realisation and pay-back of investments. Nevertheless, new accounting metrics and smart applications could also assist the design of property or infrastructure investment in order to better address the risks associated with the standard Keynesian stimulus approach, which may have serious drawbacks in the case of ageing or shrinking economies. In cities with an uncompetitive local economy and negative elasticity to globalisation, public sector investment does not necessarily generate catalytic, private-led economic growth, but may end up generating the more than proportional growth of borrowings and liabilities, and weakening the city's cash-generating capacity, which is probably already limited to start with (thus conducive to a further deflationary impact). Therefore, the smart city agenda should be customised so as to take account of the location-specific conditions of the urban economy, and where appropriate it should be linked to a place-based turnaround agenda focusing on achieving productivity and efficiency gains. This should be implemented through tailored, impact-driven investment permitting the optimal use of idle or underutilised resources: for example, derelict or under-used physical assets with long residual lives may offer opportunities for new business and job creation if correctly priced. However, urban economies are subject to increasingly rapid swings affecting employment and local tax base, making them vulnerable to scale diseconomies, asymmetric shocks and rigid fixed cost structures. Thus a turnaround strategy aimed at improving a city's long-term performance through a value creation approach, can be thought of as comprising a number of functional dimensions: i) value added from export activities; ii) value added from domestic activities; iii) labour productivity; iv) capital depreciation/amortisation; v) risk control; vi) financial asset performance; vii) transfers – such as inward investment, social security transfers, government/tax transfers, etc.); viii) brand value management, including the marketing of symbolic capital); ix) spatial "seignorage", including the capture of urban rents through the sale of building rights and other land value capture mechanisms[20]. The value creation objective takes on even more importance, given that the reduced scope for fiscal transfers and stringent regulatory changes – such as the local authorities' balanced budget requirements – will make traditional Keynesian policies increasingly difficult to implement in cities. Thus the monetary policy which has often stimulated increases in current expenditure in the past, will have to give way – assuming that a loose monetary policy will continue for some time – to a clearer focus on investment capable of reducing gaps in competitiveness and increasing cash-generation.

The performance of urban areas and urban cycles is largely dependent upon the demographic features of such areas' populations, in line with the classic Modigliani approach to the economics of the life cycle[21]. The consumption and investment patterns, and the net credit/debit position, of an urban economy vary according to the shape of the population's age pyramid. It is typical for mature baby-boomers to migrate from expensive metropolitan areas to less expensive locations with better climates, and to smaller settlements where they can downsize, retire or open small entrepreneurial activities with the proceeds of the sale of their metropolitan assets. These transfers have significant aggregate effects on the capital structure and financial performance of different territories (Davezies, 2012). The lack of a pyramidal control chain among city agents does not preclude the use of urban modelling measures to draft approximated pro-forma consolidated financial statements and indicators, possibly with the help of geo-referenced data. Such modelling measures should strive to exploit the existence of local data in central banks, social security bodies, national statistical offices, health institutions, credit and insurance institutions and so on, in order to extract and consolidate their wealth of information so as to assist the design and implementation of city investment strategies. This element is particularly crucial, because modern metropolitan areas are particularly sensitive to agglomeration and scale economies, which make them specifically vulnerable to the potential increase in fixed unit costs connected to population ageing and the loss of private sector employment, as shown by the financial impact of the recent recession on many Southern European cities.

INCREASINGLY CONNECTED: GLOBALISATION AND CITIES

Globalisation and Cities

In previous sections of this chapter it has been argued that in a globalised world, where fiscal transfers from higher governmental levels are increasingly scarce, a city's cash generating capacity is a key determinant for the feasibility of long-term sustainable development. This capacity is represented by the "organic" net export of goods and services, plus other net wealth transfers, including net human capital gains, financial and pension transfers, net corporate direct investment, tourist expenditures, etc. These transfers are mostly made towards competitive urban systems characterised by dynamic job markets, good governance and favourable tax facilities. The presence of natural and cultural amenities, or city-specific symbolic values (e.g. religious centres), also impacts migration flows. Thus individual cities are subject to continuous competitive pressures at the territorial level, and need to adjust their response to the challenges of a globalised economy, in an environment where fiscal transfers from the centre are more difficult to attain, and therefore policies to attract and retain assets – such as incentives to attract companies to locate in the city – will have to be designed using endogenous mechanisms. This makes urban asset management along the lines of the corporate approach advocated in this chapter a core priority for successful city transformation. If these pressures are successfully addressed, this process can lead to a reinforcement of a city's economy, although it also constitutes a potential threat to the stability of more fragile urban systems. For instance, in the case of a contraction of business activity, adjustment would be facilitated by flexible infrastructure service provision, possibly combined with the lower remuneration of other production factors, but lower salaries would produce further outward migration of talent and could lead to a further contraction. The strength of these forces can lead to intense labour migration similar to that experienced in the former DDR after German reunification (Uhlig, 2008; Dornbusch & Wolf, 1994; Bensemann & Kiesewetter, 2008) or in the shrinking metropolitan systems of the US "rust belt" in the 1970s and 1980s. Adjustment in integrated economies without automatic territorial stabilisers – one of the key differences between the Eurozone and federal systems like the USA – can cause disruptive falls in property prices, asset under-use, social and financial distress and municipal bankruptcies. Cities with limited cash-generating activities that are unable to trigger an effective economic turn-around, are forced to expand their external borrowing position and/or enter into a progressive deflationary cycle of low wages and low asset prices. This can be exacerbated by the out-migration of human capital and the increase in average fixed costs as a result of shrinkage. In this context, a valid strategy may be represented by proactive policies to facilitate shrinkage, such as those adopted by the German federal government to support East German cities during the post-unification period, and the transition towards a more "autarchic" equilibrium facilitated by asset deflation or currency devaluation.[22]

The Impact of Global Monetary Factors on Urbanisation

The extent to which recent world urbanisation patterns have been influenced by monetary policies in the USA and other industrialised countries, has generally been underestimated (Eichengreen, 2013). Urbanisation rates, particularly in China and other fast-growing Asian economies, have accelerated, driven by the spectacular increase in US imports from low labour cost economies, which has driven up demand for city-based manufacturing production. The increasing demand for urban labour in the export-driven emerging economies has been matched by the ample availability of credit for urban development projects from the international banking system (resulting in an impressive increase in dollar-denominated endogenous money, thanks to the collateral role played by rapidly inflating real estate assets in a low interest rate, low inflation environment). Since the early 1980s, massive trade surpluses in US dollar denominated deposits, and the accommodative monetary policy of Alan Greenspan and his successors, have provided ample ammunition to worldwide speculative urban investment, facilitating unsustainable urban development patterns and real estate excesses[23], often driven by option value considerations rather than core operating profitability. In emerging economies, speculative profits are generated by the purchase, and sometimes the illegal seizure of, informal settlement areas and agricultural land on the city fringe, in the expectation of land use changes possibly fostered by unorthodox practices. Speculative urban investment triggered by low interest rates may be undesirable both from a social point of view (implying, as it does, gentrification, displacement of low-income residents, etc.), and from the environmental perspective. The carry trade[24] on agricultural land around emerging country megacities and urban sprawl is favoured by low interest rates and the expected capital gains deriving from future land use changes. There is thus a monetary link between monetary policy and global urbanisation, as suggested by Paul Bairoch over 30 years ago with the expression "urban inflation"[25]. A persistent accommodative money supply and the ready availability of credit have turned urban investment, normally playing a Keynesian anti-cyclical role during recessions, into a pro-cyclical "push" function, bringing about the acceleration of urban capital accumulation in mega-cities. Both the IMF and other observers have raised concerns regarding western central banks' lack of concern for the indirect effects of their policies on the financial stability of emerging economies. The related adjustment could be painfully long, with the deleveraging of the banking system's endogenous money in large economies being counterbalanced by an expansion of the central banks' exogenous money supply and balance sheets[26].

SMART AND SUSTAINABLE: THE EUROPEAN DIMENSION

Towards Sharper Spatial Divergence in Europe

In a previous article (Leanza & Carbonaro, 2013), the authors discussed some of the current spatial transformation trends in the EU, together with the risk of increasing territorial divergence. The establishment of the Eurozone, by eliminating the possibility of competitive devaluations by Member States, has progressively determined a marked deterioration in the relative competitive position of many formerly thriving industrial centres in Southern Europe. While the structural adjustments in principle required to make a single currency area viable, were not carried out during the years immediately after the introduction of the Euro, massive inflows of financial capital into the Southern economies led to above-average wages and inflation, thus progressively weakening their competitiveness. Overheating of property prices was particularly obvious in Spain and Ireland. This phenomenon was connected to the financial markets' misperception that the risks associated with cross-border investments in the Euro area had been eliminated (Krugman, 2012 & 2013). According to Krugman, the gradual accumulation of these imbalances over a long period and the accommodative policy of the ECB allowing above-target inflation in some countries, led to the most powerful asymmetric financial shock in European post-war history, when capital flows from the core to the peripheral countries[27] suddenly stopped after the Greek sovereign debt crisis. It is increasingly clear that one of the key problems with the Eurozone is its sub-optimal nature[28] as a currency area, in terms of factor mobility (labour) and, in particular, fiscal integration[29], necessary to preserve financial equilibrium in the countries adhering to a currency union (Kenen, 1969) in the event of asymmetric shocks. In the US economy, as opposed to the Eurozone, in the event of asymmetric shocks affecting specific territories, substantial compensating flows are automatically activated through the federal budget, e.g. through reduced tax contributions made by the States, Medicaid and Social Security transfers, and the federal guarantee on bank deposits[30]. At the same time, the US central government's borrowing capacity is unaffected, in view of the Federal Reserve's role as lender of last resort – a function that the ECB is prohibited from playing by the Maastricht Treaty and the current weakness of the EU's institutional fiscal stabilization mechanisms. Thus, in many ways what happened in Ireland and Spain is similar to the crisis following the US Savings and Loans debacle during the eighties in states like Texas. Despite the severity of the collapse, wider disruption at the time was prevented by the intervention of the Treasury and the Federal Deposit Insurance Corporation.

The single currency and European integration have modified and accelerated capital and resource flows (including labour) among different European metropolitan areas, determining a substantial collapse in credit demand for new projects in weaker urban areas[31] in response to changes in their relative productivity and borrowing capacity/financial standing. One example of this is the evolution of market shares in the EU automotive industry, where capacity has significantly shifted from Italy, France and the UK towards the German, Czech and Slovak industrial centres. A historical industrial city like Turin, once a powerful attractor of capital and labour directly and indirectly linked to the automotive cluster, has experienced a decrease in productive capacity and a reversal in specialised human capital flows. On the other side of this shift, German export cities such as Hamburg, Munich or Stuttgart, compared to peripheral areas of the country, enjoy higher organic profitability, i.e. place-specific returns on investment, lower local systemic risk, substantial inward investment and financial inflows, and robust capital gains represented by the growing levels of urban rent and the overall option value of urban assets. Banks in Germany can thus provide reasonable investment terms to urban project promoters and borrowers, while local authorities can use value capture and tax mechanisms to support social and infrastructure spending while having limited recourse to additional debt. The risk of an increasing territorial duality has been clearly identified by the economic geographer Laurent Davezies in his work on the French "territorial fracture" (Davezies, 2012). The increasing divergence in economic performance across European urban systems can only be addressed by reinforcing the quality of capital allocation decisions and urban asset use, matched by a reduction in the city's fixed costs and overheads. Salary cuts, if not compensated by a proportionate reduction in living costs and asset prices, determine a further acceleration in human capital drain and worsen urban competitiveness. Thus innovative holistic strategies are increasingly needed in order to maintain the long-term welfare and employment opportunities of the residents of weaker cities[32], while at the same time reducing the risk of spiralling urban debt.

Systemic Implications

Confronted with a growing divergence in territorial risks, the banking sector has been in most cases unable to preserve or set aside the regulatory capital and reserves required to address the necessary structural changes in urban environment and strategies. In practice, banks have reacted to the crisis and the worsening quality in their loan portfolios by reducing credit volumes, increasing credit spreads and bringing to a virtual standstill new lending in vulnerable territories[33]. Unaffordable credit spreads and the lack of banking equity have hampered economic recovery in Southern

Europe, where the risk-weighted cost of capital has been incompatible with the normally expected investment profitability and the loss of metropolitan agglomeration economies[34]. Addressing this situation requires appropriate place-focused risk modelling and "patient" investment devoted to transformational turn-around strategies (Chang, 2010) focused on institutional and economic reforms and the reduction of urban "break-even" costs. Quantitative easing and near-zero interest rates are not providing material benefits to weaker urban economies, while capital moves to safe havens, often providing additional encouragement to speculative activities. Job migration and ageing will affect pension systems in weaker countries where payment obligations are bound to grow more rapidly than actual contributions, while low interest rates increase the net present value of future notional liabilities and reduce the return on existing pension assets. Ultimately, the negative balance may have to be covered through an increase in general taxation[35], which will impact competitiveness and human capital accumulation. Similarly, a slow-down in Asian markets could lead to problems even in currently successful European export cities and countries, whose productive structure depends largely on emerging nations' urban investment demand fuelled by accommodating monetary policies in Western countries.

Generic investment strategies based on poor diagnostics risk producing a long sequence of project failures, oversized capital assets, cost overruns, and phantom investment, and at a later stage derelict land, write-offs and the need to provide for rapidly obsolescent infrastructure. Worryingly, in western economies families are confronted with a rapid increase in the costs of child rearing, with its increasing educational and human capital investment. The growth of these costs is above official retail inflation rates, as the real human capital investment deflator is pushed upwards by the structurally lower productivity growth in those areas – education, health, personal care – needed to promote human capital investment. This pressure clearly helps account for the transition to ultra-low fertility behaviour in some Western countries.[36]

The role of rents and option schemes in the urban economy helps explain the presence of urban development models which may lead to economically unstable systems. The simple "perpetuity" formula $K=\pi/i$ shows how under certain circumstances, persistently low interest rates increase the capital value of a given rent π. *Ceteris paribus* near-zero interest rates may generate a powerful incentive for rent seeking and a shift from a society of producers to one of "rent earners" encouraged to exploit tax and financial leverage (Stiglitz, 2012a). Local rent factors also reinforce the convenience of investing in urban branding operations in the case of those cities with a high "symbolic" value (London, Barcelona, Paris, Venice, Berlin, etc.) (Harvey, 2012). The corporate finance approach to assessing a city's performance shows how in a low interest rate environment, land and assets may be deemed to constitute a form of "wealth parking" by investors for purely speculative reasons[37]. Price volatility, low interest rates, long exercise periods and the availability of loans lead to the option value of land becoming a significant component of a city's market value, to the detriment of long-term sustainable investment. This consideration suggests a possible economic reason for the decoupling of land taking and soil sealing from real long-term returns on urban investment. The use of smart technology can provide transparency and democracy in these processes while lowering urban management and living costs.[38]

CONCLUSION

Despite the decline of certain urban areas whose economic base was excessively dependent upon traditional manufacturing industry, in the latter decades of the last century many cities in Europe generally managed to transform their economies to adapt to a service centred economy. In this process, they benefitted from positive demographics and migration flows and relatively easy access to finance. In more recent years, however, under the combined pressure from intensifying globalisation, the outsourcing of production to the emerging economies, the EU monetary union and the onset of the great recession, several cities have been confronted with the risk of a relatively rapid deterioration in their economic performance and quality of life – and not only in Southern European countries. In itself, urban technology and smart city concepts do not automatically ensure that cities are going to engage in transformative investing leading to long-term balanced development. In order to achieve this, they will have to re-think their affordability and social inclusiveness policies, and to adopt sustainability and place-based investing models.

In Europe, the persistency of accommodative monetary policies has indirectly accelerated factor mobility and resource transfers towards urban systems enjoying better productivity and employment fundamentals. Particularly in Southern Europe, any new measures should help the economies to deal with the complexity of open, highly integrated markets in order to coherently manage the risks of out-migration of talented human capital and jobs towards high productivity poles. The EU and its Member States will continue providing political and financial support to urban areas, but – also in view of stricter budget constraints on central government – could require enhanced governance and instruments to direct urban capital allocation processes and to preserve the financial stability, environmental quality and social inclusiveness of urban systems.

City-tailored strategic investing could prove to be a better way of addressing the risks faced by the more vulnerable urban areas, in view of the limitations and unintended consequences of macro policies. "Smart city" concepts where technology and technological innovation is given a role in fostering sustainable and inclusive urban development can be used to direct capital allocation through a bottom-up mechanism exploiting the opportunities offered by a place-based approach to investment. The implementation of an innovative digital agenda, tailored to the needs of metropolitan areas and labour markets, can help recovery and create jobs in cities, while supporting the rationalisation of their physical infrastructures and reducing operating and maintenance costs. In the future, the core business in the EU urban sector is likely to shift from building to managing cities, with consequences in terms of the required mix of skills, implementation vehicles and managerial know-how.

City-tailored innovative technologies, socially participative solutions, the involvement of impact investors, and innovative funding, may all be perceived as threats by many incumbent operators, but are more likely to help economic recovery after a long recession. The success of a bottom-up smart city strategy will depend ultimately on the right mix of a number of factors – the participative approach, high customisation (smart city as a place-based strategy vs. horizontal policies), the use of open source solutions, the capacity to mobilise idle urban assets, enhancing the flexibility of fixed capital, the attraction of external investors, the development and use of sustainable return metrics, and the establishment of dedicated financial vehicles capable of strategic investing.

Considering that Europe may be faced with a long period of slow growth, low inflation and constant financial instability (Münchau, 2014), it is crucial that the allocation of scarce capital resources focuses on those assets that guarantee long-term sustainable returns. In thriving urban areas, low interest rates fuel speculative investment aimed at gaining urban optional value and rents. It has been observed that in principle restrictive monetary policies would be required for such metropolitan areas resembling mega-states (Kaminska, 2014). However, such city-specific monetary adjustments are not implementable in practice, and in their absence smart city technology can provide transparent, timely crucial information regarding urban investment opportunities to special municipal financial institutions which can then act to preserve overall financial stability, and point capital accumulation in the right direction. Similarly, in vulnerable urban territories the same technology and institutional innovation can lead to the creation of "urban development banks" ensuring the sustainability of transformative investment for urban turn-around strategies.

It also appears that the rationalisation of public sector assets and services constitutes a core area for smart-city investing. It has been argued recently, by Larry Summers (2013), that long-term productivity growth differentials across sectors can have highly destabilising effects on welfare and distribution. There is thus a need to address a double divergence affecting territorial development and having serious effects within the EU. One is the already mentioned divergence between territories, which has revived the dualism between Northern and Southern countries and cities within the EU, following a long period of apparent convergence. The other is the divergence between the sectors where productivity growth is structurally high – mostly in the market driven economy and manufacturing – and service-based sectors, often providing essential support to the level and quality of human capital necessary for a modern economy to operate successfully. Here, the lower pace of productivity growth has led to imbalances in affordability for the public at large, while the public sector is unable to compensate for the sharp increases in the corresponding prices associated with this process. This double divergence particularly affects city economies, and the smart city concept has the vital role of preserving competitiveness in cities, or of limiting the highly disruptive impact of these factors on the competitiveness of weaker urban systems, by allocating capital – in particular public capital – in more productive, sustainable ways. "Fordian-Keynesian" smart-city approaches, led by technological, product standardisation and taste homogenisation factors designed to take advantage of urban scale economies, may prove economically viable in a number of selected, thriving global cities. More generally, the role of participative smart-city strategies can provide a wider boost to the quality and sustainability of daily life in cities through improved "cross-sector" and "time-scale" city integration/planning, the greater transparency of information/opportunities, and enhanced urban affordability. Smart, bottom-up approaches will also play a crucial role in preserving urban jobs (particularly in innovative and low productivity areas/sectors) and their social dimensions, thanks to place-based productivity gains in key public domains (such as education, health, public transport, energy management and concessionary activities) as well as through an increased degree of citizen participation and collective response. In practice, implementing a corporate finance approach to city investing means that the city manager should look at the city as a diversified, dynamic portfolio of activities, some mature and cash-generating (such as standard utilities like water cycle management), others more innovative yet still potentially cash-generating, such as energy efficiency projects, and yet others innovative and cash absorbing in their development phase, such as renewables – together with activities that while essential for the economy of the city, are likely to remain cash-absorbing and in need of support through cross-subsidisation or transfers (such as public transport or the delivery of public good-type services). The use of innovative instruments based on the experience gained in 2007-2013 with the JESSICA urban development funds (as illustrated in the Annex), could become a key aspect of these strategies, together with the use of participative funding mechanisms designed to align investment choices to the needs and the ability to pay of city residents.

In the previous sections we have presented a research agenda designed to enable smart, socially inclusive, sustainable cities to contribute to the balanced, equitable development of the European economy. In order for cities to play this role it is necessary to start from a vision of the city as a system of interlinked assets, and from the need to manage these assets in a sustainable way using a methodology broadly based on corporate finance principles. This vision should facilitate better bottom-up policy delivery – which appears better suited to taking advantage of the cross-sector complementarities in the spatial economy – and ultimately help European cities to deal more effectively with the urban challenges that have emerged in recent years.

EU SUPPORT FOR THE SMART CITY

The EU legislative package for the next programming period 2014-2020 gives much greater importance to the territorial and urban agenda, and to the use of financial instruments to deliver the objectives of the Cohesion Policy and the 2020 European agenda "Smart, sustainable and inclusive growth"[39]. Cities will be able to contribute land or real estate in relation to investments, with the objective of supporting urban development or urban regeneration, where the land or real estate forms part of the investment, and to hence capitalise financial instruments, including financial instruments for urban and territorial development[40]. These contributions can be used to cover the Cohesion Policy's national co-financing requirement,[41] meaning that a "smart city" strategy can potentially benefit from substantial EU budgetary resources.

Under the EU's 2014-2020 budget, the Cohesion Policy will invest up to €351.8 bn in Europe's Member States, their regions and cities, in order to deliver the EU-wide goals of growth and jobs, as well as tackling climate change, energy dependence and social exclusion. Taking into account potential co-financing resources, the overall potential for investment may be estimated at more than €500 bn. The EU resources are targeted at sectors considered critical for the achievement of the 2020 European agenda. In particular, investment under the European Regional Development Fund (ERDF) will concentrate on 4 key priorities: innovation and research, the digital agenda, support for small and medium-sized businesses (SMEs), and the low-carbon economy, depending on the category of region (Less Developed: 50%, Transition: 60%, and More Developed: 80%). An estimated minimum of €100 bn[42] will be dedicated to these priorities, of which at least €23 bn will support the shift to a low-carbon economy (energy efficiency and renewable energies).

The Commission works with Member States to design national programmes, to be co-financed by EU budget resources, in support of key structural reforms. In the case of "smart specialisation" strategies to identify particular strengths and potential, business-friendly reforms, transport strategies, measures to improve public procurement systems, compliance with environmental laws, strategies to fight youth employment, early school leaving or to promote gender equality and non-discrimination are all necessary preconditions. A Common Strategic Framework provides the basis for better coordination among the European Structural and Investment Funds ("ESI" Funds: ERDF, Cohesion Fund and ESF as the three funds under the Cohesion Policy, together with the Rural Development and Fisheries Funds). Through the European Social Fund (ESF), the Cohesion Policy will provide some €80 bn in support of EU priorities in the field of employment, for example through training and life-long learning, education and social inclusion (at least 20% of the ESF in each Member State will have to be used to support this objective). The EU framework also provides for enhanced coordination with other EU instruments such as Horizon 2020, the Connecting Europe Facility and the Programme for Employment and Social Innovation.

Using the experience gained in managing, among other things, the Joint European Support for Sustainable Investment in City Areas ("JESSICA") project and the Urban Development Funds implemented following said project, new financial instruments for urban and territorial development aligned with the concept of "Urban Impact Funds" (see below for a description of the impact investing concept) can help local authorities design and implement investment strategies combining financial and non-financial performance in the most effective way. This is based on investment portfolios driven by revenue-generating requirements and financial performance metrics, as well as non-financial performance metrics linked to the smart development objectives of cities and metropolitan areas. At the beginning of 2014, some 45 JESSICA financial instruments (Urban Development Funds) were operational in 11 countries and some 55 regions in the EU, accounting for total committed funding of approximately €1.8 bn, mostly from European Structural Funds.[43] This already represents a very encouraging result for an innovative project focussed on city sustainability like JESSICA. The European Authorities can learn some important lessons from this experience, in order to develop fully-fledged Urban Impact Funds for the implementation of a smart city agenda targeting sustainability and social inclusion.

Impact investments are investments in companies, organizations and funds designed to generate a social and environmental impact together with a financial return. Impact investments can be made in both emerging and developed markets, and can target a range of returns from below market to market rate, depending on the circumstances. Urban Impact Funds should be designed and tailored to local authorities' needs. In our view, one of the weaknesses of the way in which those authorities responsible for the management of operational programmes identify and finance investment opportunities, lies in their limited coordination with the credit sector and other city stakeholders. This is due partly to the fact that the traditional grant-centred project funding approach has not stimulated the systematic application of sound financial analysis (e.g. ROI, banking viability, etc.), and linked this to project selection and structuring. The dialogue with private investors and the banking sector has also been too occasional, and learning-by-doing opportunities that can only be captured through regular co-operation have been missed, and with them the opportunity to use scarce EU resources more effectively. In the countries and regions where they have been implemented, the financial instruments promoted by the JESSICA project have gradually started to change the way EU budgetary resources are employed, and have stimulated the transition from traditional grant funding to revolving instruments capable of attracting additional financial resources and reconstituting the value of the instrument, allowing its further re-use.

Impact instruments of the type promoted through the JESSICA project can be employed to provide finance at sub-commercial terms, now allowed under State Aid regimes approved by the European Commission.[44] This will enable financial instruments, including those for urban and territorial development, to offer terms and conditions compatible with the lower organic returns from urban projects in non-core countries. The process can be expected to be strongly supportive of job creation and overall EU growth, as in the long term it may help stabilise financial markets. In this challenging environment, the role of financial instruments for cities must be tailored in order to address the concerns of both the authorities and investors. To give an example, Cohesion Policy resources channelled through JESSICA can be offered as subordinated and junior capital, in order to adapt the overall risk profile to the requirements of different classes of co-financiers. This should balance the risk-reward trade-off for many strategic projects which while essential for the sustainable transformation of cities, would not be delivered through unassisted market mechanisms. Typically, the availability of a subordinated tranche generates significant relief in terms of risk-weighted-assets (RWA) for the co-financing bank, reducing *ceteris paribus* capital adequacy requirements and making lending more attractive.

A very powerful product for the implementation of the Smart City agenda in 2014-2020 concerns the possibility of using ESI Funds to subscribe capital instruments (e.g. hybrid Tier 1 instruments) issued by a municipal bank, SME guarantee fund or other impact investment vehicle (including those having recourse to crowd-funding mechanisms). This mechanism would facilitate setting up and capitalising vehicles investing in urban transformation in support of the sustainable, smart city agenda, boosting the availability of "impact-related" regulatory capital for those banking intermediaries willing to dedicate their lending to these policy objectives, thus leveraging additional lending capacity in that direction. Subscription could be implemented in tranches or through securities convertible into equity instruments, aligned with the co-lending activity and the capital absorption targeted by the authorities and investors. To be clear, this would be conditional on employing the increased lending capacity for impact investing supporting long-term sustainable development strategies. In this context it is worth noting that the pricing structure would also need to be harmonised in order to reflect the conversion into Tier 1 capital, and that the relevant regulatory implications would need to be analysed in detail (conditionality, pricing, etc.). For the reasons illustrated at length in the previous sections, a strengthening of European financial instruments for territorial cohesion is needed in order to facilitate European economic recovery, with cities and innovative investors as the engines of this process. These mechanisms should operate at a decentralised or "shared" level, in line with the mission and objectives of the EU's Cohesion Policy. These financial instruments should be structured in such a way as to unlock their full potential for promoting transformational investment in cities.

REFERENCES

Acemoglu, D., & Robinson, J. A. (2012). *Why Nations Fail: The Origins of Power, Prosperity, and Poverty*. New York: Crown Business.

Alesina, A., Barro, R. J., & Tenreyro, S. (2002). Optimal Currency Areas. Working Paper 9072. The National Bureau of Economic Research.

Bairoch, P. (2013). *The Economic Development of the Third World Since 1900*. Routledge.

Bayoumi, T., Dell'Ariccia, G., Habermeier, K. F., Mancini Griffoli, T., & Valencia, F. (2014). *Monetary Policy in the New Normal. Staff Discussion Notes, 14(3)*. International Monetary Fund.

Begg, I. (2002). *Urban Competitiveness: Policies for Dynamic Cities*. Bristol: Policy Press.

Benevolo, L. (2011). *La fine della città*. Bari: Laterza.

Bensemann, T., & Kiesewetter, D. (2008). *Who has really paid for the Reconstruction of East Germany? Expected and Realized Returns on Real Estate Investments in East and West Germany in the 1990s. FEMM Working Papers 08007*. Otto-von-Guericke University Magdeburg, Faculty of Economics and Management.

Bonvalet, C., Drosso, F., Benguigui, F., & Huynh, P.-M. (2007). *Vieillissement de la population et logement: Les strategies résidentielles et patrimoniales*. La Documentation Francaise.

Bordo, M. D., & Jeanne, O. (2002). *Monetary Policy and Asset Prices: Does "Benign Neglect" Make Sense?* International Monetary Fund.

Bourdeau-Lepage, L., & Huriot, J.-M. (2006). *Megacities vs Global Cities. Development and Institutions*. Vienna, Austria: European Regional Science Association.

Calvo, G. A., & Reinhart, C. M. (2002). Fear of Floating. *The Quarterly Journal of Economics*, *117*(2), 379–408. doi:10.1162/003355302753650274

Campos Venuti, G. (2010). *Città senza cultura*. Bari: Laterza.

Chang, H.-J. (2010). Financial markets need to become less, not more, efficient. Chapter 22 in H.-J. Chang, 23 Things They Don't Tell You About Capitalism (pp. 230-241). London: Penguin.

Davezies, L. (2012). *La crise qui vient: La nouvelle fracture territoriale*. Paris: Seuil.

Davis, M. (2006). *Planet of Slums*. New York: Verso.

Dobbs, R., Smit, S., Remes, J., Manyika, J., Roxburgh, C., & Restrepo, A. (2011). *Urban world: Mapping the economic power of cities*. McKinsey Global Institute.

Dornbusch, R., & Wolf, H. C. (1994). East German Economic Reconstruction. In O. J. Blanchard, K. A. Froot, & J. D. Sachs, The Transition in Eastern Europe, Volume 1 (pp. 155-190). University of Chicago Press.

Dowell, M., & Sung Ho, R. (2008). Aging Baby Boomers and the Generational Housing Bubble. *Journal of the American Planning Association*, *74*(1), 17–33. doi:10.1080/01944360701802006

Eichengreen, B. (1991, January). Is Europe an Optimum Currency Area? Working Paper 3579. The National Bureau of Economic Research.

Eichengreen, B. (2013). *Does the Fed Care About the Rest of the World?* The National Bureau for Economic Research.

Eichengreen, B. (2014). *The Dollar and the Damage Done*. Project Syndicate.

European Central Bank. (2009). *Housing Wealth and Private Consumption in the EURO Area* (pp. 59–71). ECB Monthly Bulletin.

Garreau, J. (1991). *Edge City: Life on the New Frontier*. Anchor Books.

Glaeser, E. (2008). *Cities, Agglomeration and Spatial Equilibrium*. Oxford University Press.

Glaeser, E. (2011). *The Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier and Happier*. New York: Penguin Group Inc.

Goetzmann, W. N., & Newman, F. (2010). *Securitization in the 1920's*. The National Bureau of Economic Research. doi:10.3386/w15650

Goodwin, N. R. (2003). *Five Kinds of Capital: Useful Concepts for Sustainable Development*. Global Development and Environment Institute.

Harvey, D. (2010). *The Enigma of Capital and the Crises of Capitalism*. Oxford University Press.

Harvey, D. (2012). *Rebel Cities: From the Right to the City to the Urban Revolution*. New York: Verso.

Jacobs, J. (1961). Gradual money and cataclysmic money. Chapter 16 in J. Jacobs, The Death and Life of Great American Cities. Vintage Books.

Kaminska, I. (2014). A game of mega-city states. Retrieved from Financial Times Alphaville: http://ftalphaville.ft.com/2014/06/18/1879892/a-game-of-mega-city-states/

Kenen, P. (1969). The Theory of Optimum Currency Areas: An Eclectic View. In R. A. Mundell & A. K. Swoboda (Eds.), *Monetary problems of the international economy*. Chicago: University of Chicago Press.

Knetsch, T. A. (2009). *Trend and cycle features in German residential investment before and after unification*. Frankfurt am Main: Deutsche Bundesbank, Economics Department.

Koo, R. C. (2013). *Central Banks in Balance Sheet Recessions: A Search for Correct Response*. Nomura Research Institute.

Krugman, P. (2013). Currency Regimes, Capital Flows, and Crises. *14th Jaques Polak Annual Research Conference*. Washington D.C.: International Monetary Fund.

Krugman, P. (2013). Revenge of the Optimum Currency Area. In D. Acemoglu, J. Parker, & M. Woodford, NBER Macroeconomics Annual 2012, Volume 27 (pp. 439-448). University of Chicago Press. doi:10.1086/669188

Kuester, K., Müller, G. J., & Stölting, S. (2007). Is the Keynesian Phillips Curve Flat? Working Paper Series 809, pp. 3-33.

Leanza, E., & Carbonaro, G. (2013). Making European Cities more Affordable. *Productive and Sustainable. L'industria*, *2*, 275–294.

Lefebvre, H. (1991). *The production of space*. Blackwell.

Mankiw, N. G., & Weil, D. N. (1989). The Baby Boom, the Baby Burst, and the Housing Market. *Regional Science and Urban Economics*, *19*(2), 235–258. doi:10.1016/0166-0462(89)90005-7 PMID:12283640

McCarthy, J., & Peach, R. W. (2002). *Monetary Policy Transmission to Residential Investment*. FRBNY Economic Policy Review.

Milcheva, S., & Sebastian, S. (2010). *Housing Channels of Monetary Policy Transmission in European Industrial and Transition Countries*. European Real Estate Society.

Minsky, H. P. (1992). The Financial Instability Hypothesis. Working Paper (74). The Jerome Levy Economics Institute of Bard College.

Mishkin, F. (2001). *The Transmission Mechanism and the Role of Asset Prices in Monetary Policy*. The National Bureau of Economic Research. doi:10.3386/w8617

Mishkin, F. (2007). *Housing and the Monetary Transmission Mechanism*. The National Bureau of Economic Research. doi:10.3386/w13518

Mishkin, F. S. (2000). *Lessons from the Asian Crisis*. The National Bureau of Economic Research. doi:10.3386/w7102

Mishkin, F. S. (2011). *Monetary Policy Strategy: Lessons from the Crisis*. The National Bureau of Economic Research. doi:10.3386/w16755

Modigliani, F. (1986). Life Cycle, Individual Thrift, and the Wealth of Nations. *The American Economic Review*, *73*(3), 297–313. PMID:17744469

Modigliani, F., & Miller, M. H. (1958). The Cost of Capital, Corporation Finance and the Theory of Investment. *The American Economic Review*, *48*(3), 261–298.

Mohan, R., & Kapur, M. (2014). *Monetary Policy Coordination and the Role of Central Banks*. International Monetary Fund.

Moretti, E. (2012). *The New Geography of Jobs*. Houghton Mifflin Harcourt.

Münchau, W. (2014). Europe faces the horrors of its own house of debt. Financial Times. Retrieved from http://www.ft.com/intl/cms/s/0/beef494e-f255-11e3-9e59-00144feabdc0.html#axzz3BVLfYQ00

Mundell, R. (1961). A Theory of Optimum Currency Areas. *The American Economic Review*, 657–665.

Neumark, D., & Simpson, H. (2014, April). Place-Based Policies. Working Paper No. 20049. The National Bureau of Economic Research.

OECD. (2009). *How Regions Grow: Trends and Analysis*. OECD.

OECD. (2013). *Definition of Functional Urban Areas (FUA) for the OECD Metropolitan Database*. OECD.

Ōmae, K. (1995). *The End of the Nation State: The Rise of Regional Economies*. Simon and Schuster.

Piketty, T. (2014). *Capital in the Twenty-First Century*. Belknap Press.

Posen, A. S. (2003). *It Takes More than a Bubble to Become Japan*. Institute for International Economics.

Reinhart, C. M., & Rogoff, K. (2009). *This Time Is Different: Eight Centuries of Financial Folly*. Princeton University Press.

Rockoff, H. (2000). *How Long Did It Take the United States to Become an Optimal Currency Area?* Historical Working Paper 124. The National Bureau of Economic Research.

Sarrazin, T. (2012). *Europa braucht den Euro nicht: Wie uns politischesWunschdenken in die Krise geführt hat*. DVA.

Sassen, S. (2001). *The Global City: New York, London, Tokyo*. London: Princeton University Press. doi:10.1515/9781400847488

Sassen, S. (2002). *Global Networks, Linked Cities*. London: Psychology Press.

Saunders, D. (2010). *Arrival City: The Final Migration And Our Next World*. London: William Heinemann.

Sharpf, F. W. (2013). *Political Legitimacy in a Non-optimal Currency Area*. MPIfG Discussion Paper 13/15. Köln, Max Planck Institute for the Study of Societies.

Stiglitz, J. E. (2012a). Rent Seeking and Making of an Unequal Society. In *The Price of Inequality: How Today's Divided Society Endangers Our Future*. W.W. Norton & Company.

Stiglitz, J. E. (2012b). A Macroeconomic Policy and a Central Bank by and for the 1 percent. In *The Price of Inequality: How Today's Divided Society Endangers Our Future*. W.W. Norton & Company.

Streeck, W. (2013). *The Politics of Public Debt. Neoliberalism, Capitalist Development and the Restructuring of the State*. MPIfG Discussion Paper 13/7. Köln: Max Planck Institute for the Study of Societies.

Summers, L. H. (2013). Economic Possibilities for Our Children. NBER Reporter (4), 1-6. The National Bureau of Economic Research.

Thompson, B. (2012). *Local Asset Backed Vehicles. A success story or unproven concept?* London: RICS.

Uhlig, H. (2008). The Slow Decline of East Germany. *Journal of Comparative Economics*, *36*(4), 517–541. doi:10.1016/j.jce.2008.07.006

Veron, J. (2006). *L'urbanisation du monde*. Paris: La Découverte.

Weber, M. (1978). *Economy and Society*. University of California Press.

Zhu, H. (2005). *The importance of property markets for monetary policy and financial stability. Real estate indicators and financial stability, 21* (pp. 9–29). Bank for International Settlements.

KEY TERMS AND DEFINITIONS

Asymmetric Shocks: A change in economic conditions that affects different countries, regions and/or cities in a different way. The notion of asymmetric shocks is particularly relevant in the context of the theory of optimal currency areas. (Definition from http://www.investorwords.com/15179/asymmetric_shock.html).

Functional Urban Areas: Cities and their commuting zones, which underpin a local job market and, treated together, account for c. 60% of the EU population. (definition from http://ec.europa.eu/eurostat/statistics-explained/index.php/European_cities_%E2%80%93_the_EU-OECD_functional_urban_area_definition).

Impact Fund: A fund whose goal is to implement investments that generate a measurable, beneficial social and/or environmental impact, in addition to a financial return. (definition of the Global Impact Investing Network (GIIN)).

Integrated Planning: An approach to urban planning aimed at designing a sustainable and socially cohesive urban environment, which takes into account the linkages between a broad range of variables and stakeholders in order to achieve an optimal and community-shared outcome.

Place-Based Strategies/Investments: An approach to territorial investment where stakeholders engage in a collaborative process to address issues as they are experienced within a geographic space, be it a neighbourhood, a region, or an ecosystem. These approaches have a common set of characteristics that challenge traditional notions of evaluation. (Definition from http://www.horizons.gc.ca/eng/content/evaluation-place-based-approaches).

Territorial Diagnostics: The result of the application of a systematic methodology to the analysis of specific spatial units, such as functional urban areas, aimed at identifying key challenges and opportunities as a basis for strategic investment decisions for a certain area, city or region, in line with a place-based and integrated approach.

ENDNOTES

1 It should be pointed out that technological innovation and spatial change may create economic obsolescence involving the decommissioning of assets with a potentially useful residual life and negative overall GHG emissions balance.

2 However, some of these urban areas – particularly "mega cities" in emerging economies – have experienced rapid expansion which questions the long-term sustainability of this process. See Bordeau-Lepage and Huriot, 2006.

3 For comprehensive summaries of the macroeconomic imbalances in Europe, and of how these have been exacerbated by the establishment of the monetary union, see Streeck, 2013 and Sharpf, 2013, who also elaborate on their political implications.

4 There have been major debates among sector specialists on the precise way to configure the relationship between housing demand and demographic forecasts. See Mankiw and Weil, 1989.

5 This is the view of many architects and urban scholars. See Benevolo, 2011 and Campos Venuti, 2010.

6 "Optimism in the financial markets has the power to raise steel, but it does not make a building pay" (Goetzmann and Newman, 2009). See also Reinhart and Rogoff (2009) over the role of real estate bubbles with reference to the so-called "Big Five" (Spain 1977, Norwey 1987, Finland and Sweden 1991, Japan 1992). See also Mishkin (2000), Bordo and Jeanne (2002), Mishkin (2011).

7 On the Phillips curve, see Kuester, Müller and Stölting (2007) and Bayoumi et al. (2014).

8 See also Begg (2002).

9 For an early view of the decline of nation-states, see Ōmae (1995).

10 Most of the alpha cities cluster of the Globalisation and World Cities (GaWC) project, http://www.lboro.com/gawc/.

11 Very different from the original European "market place model" proposed by Weber (1978), as clearly evidenced in Lefebvre (1991).

12 The impact fund industry supports innovative financing approaches e.g. crowd fund-

ing, ethical and philanthropic funding, which may reduce the reliance on "globalised" banking for smart, place-based capital allocation attentive to urban sustainability and social inclusion.

13 An element which should give pause for thought to free market globalisation advocates, often in favour of higher concentration levels in global financial centres in order to capture increasing returns – see e.g. Bourdeau-Lepage and Huriot (2006) – without taking into account the corresponding credit and financial stability risks.

14 Among others, see Bonvalet et al. (2007) and Dowell & Sung Ho (2008).

15 In our approach, there are five types of capital which in principle can be evaluated by means of a NPV approach: a) Natural Capital; b) Fixed (i.e. Physical/Technical) Capital; Human Capital (in essence, the net discounted cash flow capacity of the earnings of an urban population); d) Financial (incl. tradable goods) capital; e) Spatial/locational capital. The latter captures the specific features related to city location and settlement structure (e.g. polycentrism vs. centralized territorial development). Note that this classification differs from the one proposed in Goodwin (2003).

16 Housing prices are determined by a complex mix of demand/supply factors, such as the track record of land and property as an inflation hedge and associated expectations, option values, and the symbolic value of certain cities and locations. For comments on the complexity of housing modelling, see Knetsch (2009).

17 As a result of the mismatch between outflows connected to pension payments and social security contributions paid in by workers.

18 Some of the economic relations materialize within the urban community; others involve national or international interactions. In open economies, the economic determinants of an urban system's performance are those related to its "external" exchanges and structural features.

19 GDP-based measures may lead to a distorted view, since they are not likely to fully incorporate: a) wealth changes from changing asset values (such as depreciation and amortisation, technical/economic obsolescence, damage to property); b) changes in risk exposure linked to asset volume, as well as changing risk patterns associated with social distress, climate change, etc.; c) changes in consolidated net wealth from cross-generational and territorial wealth transfers; d) location-specific wealth changes connected to movements in geographic competitiveness.

20 In principle also monetary seignorage is possible in city-states which control their monetary base (such as Hong Kong).

21 See Modigliani (1986). Demographic parameters are at the core of econometric modelling, which also explains the diversified "tuning" and transmission impact of monetary policy on individual cities, similarly to what happens for in the case of national economies.

22 This is also called "adiabatic" equilibrium, a thermodynamic term to basically describe a more sustainable downsized urban economy that is less reliant on exchanges with the external environment. Note also that given the importance of some of these cities for the national economy, these phenomena may also affect sovereign ratings and reinforce the political resistance to economic integration.

23 Jane Jacobs (1961) already acknowledged this risk in the early 1960s for the USA, when she noted that urban development land was systematically and heavily overpriced.

24 A carry trade is a strategy in which an investor borrows money at a low interest rate in order to invest in an asset that is likely to provide a higher return.

[25] In 1985 Paul Bairoch (2013) proposed a critical analysis of the challenges of the urbanisation process in the third world, also providing accurate estimates on the expected growth of the urban population.

[26] See Mohan and Kapur (2014). It is difficult for many emerging economies to optimise their monetary policies in the presence of quantitative easing by large western central banks, as higher domestic interest rates generate massive speculative capital inflows, favoured by ready access to dollar-denominated financing (Mishkin, 2011; Mishkin, 2000). Contagion effects are rapid, while asset bubbles are slow: Japanese commercial property prices fell by about 90% in two decades. See Koo (2013).

[27] This is also linked to the absence of ceilings to financing among regional central banks participating in the Euro Target 2 system, as opposed to the system operated by the Federal Reserve to avoid systemic contagion (Sarrazin, 2012).

[28] A feature identified by R. Mundell (1961). Structurally similar regions or metropolitan systems within a country or long-established monetary area, could also be seen as "not-implementable" optimal currency areas, as defined by R. Mundell (1961). Each area – for instance port cities within the same country hit by a sharp fall in maritime traffic – is affected by specific shocks in a similar way; however, within a country or currency union it would be unable to use exchange rates as an adjustment mechanism, and that is the reason why territorial stabilisers or regional policies are often employed to facilitate adjustment. The need to implement transformational strategies in cities affected by economic shocks presents similarities with the monetary policy debate on the use of floating/fixed exchange rates for small economies. See, for instance, Eichengreen (1991), Alesina et al. (2002), Calvo & Reinhart (2002), Rockoff (2000).

[29] As the European structural funds policies, due to sheer size, as well as to theoretical and practical limitations linked to both donors and recipient countries (for the latter mainly due to the slow implementation of the reform agenda), do not seem to have the capacity to redress the growing spatial imbalances.

[30] In Ireland the government's assumption of bank debts abruptly added 40 points to the Public Debt/GDP ratio. This function is now absolved by the European Stability Mechanism set up in October 2010.

[31] Induced by the so-called "consumer balance-sheet effect".

[32] As witnessed in the Detroit or Greek cases, old workers (and pensioners) are amongst the most severely affected by urban distress, their wealth being hit in four sequential stages: 1) shrinkage of the job market and wage prospects; 2) real property deflation; 3) losses on financial assets; 4) cuts in pension rights.

[33] This reaction, brought about by a traditional credit balance-sheet effect as correctly indicated by Koo (2013), has been exacerbated by the need to prepare for the parallel establishment of the more stringent, forthcoming Basel III regulatory capital requirements.

[34] Note: New hybrid regulatory capital instruments for banking urban vehicles and "employment-focussed impact funds" can be created in the EU through recourse to European structural fund resources (see Annex).

[35] Pension and health liabilities are normally financed by younger generations, and as such fall outside of the scope of standard economic analysis. Due to the baby-boomers' proximity to retirement, the lower size and

earning capacity of the new cohorts, and longer life expectancy, welfare benefits are being restructured by governments as social security's notional value may rise by up to 3.5/5.0 times the value of GDP. Welfare transfers are a key component of the aggregated demand in urban systems (as argued by P. Davezies, 2012), and their impact at the territorial level should be closely monitored/stabilized by the authorities to ensure "smart" economic planning and capital allocation.

36 On the long-term risks of unbalanced productivity growth in the economy – with human capital services characterised by low productivity growth – see Summers (2013).

37 Hyman P. Minsky (1992) argued that the longer economic expansion goes on, the greater the likelihood, and share, of speculative and Ponzi finance schemes within the system.

38 By using a corporate finance approach, a guiding principle is represented by the Modigliani and Miller theorem (1958), according to which under certain conditions the value of a firm is not influenced by its capital structure. Higher debt to equity ratios lead to relatively higher levels of the required return on equity, because of the substantially higher solvency and liquidity risk borne by the equity-holder in the case of highly geared structures.

39 In accordance with Article 6.4 of (EU) Regulation No. 1301/2013 of the European Parliament and Council of 17 December 2013, *at least 5% of the resources allocated at national level under the Investment for growth and jobs goal shall be allocated to integrated actions for sustainable urban development.*

40 On the British experience of establishing PPP vehicles where property assets are contributed by the local authorities, see Thompson B. (2012), *Local Asset Backed Vehicles: A success story or unproven concept?* RICS, London.

41 In accordance with Article 37.10 of Regulation 1303/2013 of the European Parliament and Council of 17 December 2013, contributions in kind shall not constitute eligible expenditure in respect of financial instruments, except for contributions of land or real estate in respect of investments with the objective of supporting rural development, urban development or urban regeneration, where the land or real estate forms part of the investment. Such contributions of land or real estate shall be eligible provided that the conditions laid down in Article 69(1) are met.

42 This is bearing in mind that the ERDF's budgetary resources amount to €201 bn.

43 With a market share of about 95%, the EIB is the leader in the European market for financial instruments dedicated to sustainable urban development supported by Structural Funds.

44 For details on the aid regimes approved by DG-Competition for urban development funds in England and Spain, see http://ec.europa.eu/competition/state_aid/cases/240234/240234_1247477_97_2.pdf and http://ec.europa.eu/competition/state_aid/cases/240808/240808_1295596_79_2.pdf

Compilation of References

Abdulhai, B., Pringle, R., & Karakoulas, G. (2003). Reinforcement learning for true adaptive traffic signal control. *Journal of Transportation Engineering*, *129*(3), 278–285. doi:10.1061/(ASCE)0733-947X(2003)129:3(278)

Abeje, W. (2006). What an Urban Livelihood without Adequate Breathing Space? A Reflection on the Green Areas of Addis Ababa. In *Proceedings of Green Forum Conference on Environment for Survival* (pp 1-14).

Abundance. (2014). Retrieved May 15, 2014, from https://www.abundancegeneration.com/

Acatech. (2012). *Future Energy Grid-Migration to the Internet of Energy*. Munich, Germany: National Academy of Science and Engineering.

Acemoglu, D., & Robinson, J. A. (2012). *Why Nations Fail: The Origins of Power, Prosperity, and Poverty*. New York: Crown Business.

Adams, W. M. (2006). The Future of Sustainability: Rethinking Environment and Development in the Twenty-first Century. Retrieved November 30, 2014 from http://cmsdata.iucn.org/downloads/iucn_future_of_sustanability.pdf

Aeron-Thomas, A., & Hess, S. (2009). *Red-light cameras for the prevention of road traffic crashes*. Wiley.

Agarwal, V., Banerjee, N., Chakraborty, D., & Mittal, S. (2013). USense - A Smartphone Middleware for Community Sensing. In *Proceedings of 14th IEEE International Conference on Mobile Data Management* (pp. 56-65). doi:10.1109/MDM.2013.16

Agugiaro, G. (2014). From sub-optimal datasets to a CityGML-compliant 3D city model: experiences from Trento, Italy. In Proceedings of International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (vol. XL-4, pp. 7-13).

Agugiaro, G., Nex, F., Remondino, F., De Filippi, R., Droghetti, S., & Furlanello, C. (2012). Solar radiation estimation on building roofs and web-based solar cadaster. In Proceedings of Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (vol. I-2, pp. 177-182).

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: A survey. *Computer Networks*, *38*(4), 393–422. doi:10.1016/S1389-1286(01)00302-4

Alanne, K., & Saari, A. (2006). Distributed energy generation and sustainable development. *Renewable & Sustainable Energy Reviews*, *10*(6), 539–558. doi:10.1016/j.rser.2004.11.004

Alawadhi, S., & Scholl, H. J. (2013). Aspirations and realizations: The smart city of Seattle. In *Proceedings of Hawaii International Conference on System Sciences* (pp. 1695-1703). doi:10.1109/HICSS.2013.102

Albrechts, L. (2013). Presentation at the Round Table on Co-design for social creativity. *Human Smart Cities session at FORUM PA*, Rome.

Aldrich, F. K. (2003). *Inside the Smart Home*. London, UK: Springer.

Alesina, A., Barro, R. J., & Tenreyro, S. (2002). Optimal Currency Areas. Working Paper 9072. The National Bureau of Economic Research.

Alexander, C. (1965). A city is not a tree. *The Architectural Forum*, *122*(1), 58–62.

Alexander, E. R. (Ed.). (2006). *Evaluation in Planning. Evolution and Prospects*. Aldershot: Ashgate.

Allcott, H., & Mullainathan, S. (2010). Behavior and energy policies. *Science*, *327*(5970), 1204–1205. doi:10.1126/science.1180775 PMID:20203035

Allwinkle, S., & Cruickshank, P. (2011). Creating smart-er cities: An overview. *Journal of Urban Technology*, *18*(2), 1–16. doi:10.1080/10630732.2011.601103

Almirall, E., & Wareham, J. (2008). Living labs and open innovation: Roles and applicability. *The Electronic Journal for Virtual Organizations and Networks*, *10*, 21–46.

Altschuler, A., & Zegans, M. (1997). Innovation and public management: Notes from the state house and city hall. In Althschuler, A. & Behn, R. (Eds.) Innovation in American Government. Washington, DC: Brookings Institution conference.

Alvarez, I., & Poznyak, A. (2010). Game theory applied to urban traffic light control problem. In *Proceedings of the International Conference on Control, Automation and Systems* (pp. 2164-2169).

Alwaer, H., Bickerton, R., & Kirk, R. D. (2014). Examining the components required for assessing the sustainability of communities in the UK. *Journal of Architectural and Planning Research*, *31*(1).

Alwaer, H., & Clements-Croome, D. J. (2010). Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings. *Building and Environment*, *45*(4), 799–807. doi:10.1016/j.buildenv.2009.08.019

AMBER. (2014). Retrieved May 15, 2014, from http://amberenergy.net/our-story

AMETIC. (2013). *Smart cities*. Barcelona: AMETIC.

Amin, A., & Cohendet, P. (2004). *Architectures of Knowledge*. Oxon: Oxford University Press. doi:10.1093/acprof:oso/9780199253326.001.0001

Amin, A., & Roberts, J. (2008). Knowing in action: Beyond communities of practice. *Research Policy*, *37*(2), 353–369. doi:10.1016/j.respol.2007.11.003

Ancona, S., Stanica, R., & Fiore, M. (2014). Performance Boundaries of Massive Floating Car Data Offloading. In Proceedings of IEEE/IFIP WONS. doi:10.1109/WONS.2014.6814727

Anderson, C. (2007). The End of Theory: Will the Data Deluge Make the Scientific Method Obsolete? *Wired Magazine*. Retrieved from http://www.wired.com/science/discoveries/magazine/16-07/pb_theory

Anthopoulos, L., & Vakali, A. (2012). Urban planning and smart cities: Interrelations and reciprocities. In F. Alvarez et al. (Eds.), *Future Internet Assembly 2012. From promises to reality* (pp. 178–189). New York: Springer. doi:10.1007/978-3-642-30241-1_16

Antoniadis, P., Courcoubetis, C., & Mason, R. (2004). Comparing economic incentives in peer-to-peer networks. *Computer Networks*, *46*(1), 133–146. doi:10.1016/j.comnet.2004.03.021

Aoun, C. (n.d.). *The smart city Cornerstone: Urban Efficiency*. Schneider Electric. Retrieved June 16, 2014, from http://www.digital21.gov.hk/eng/relatedDoc/download/2013/079%20SchneiderElectric%20(Annex).pdf

Arch Capital. (2007). Retrieved May 15, 2014, from http://www.archcapgroup.com/

Arnott, R., Rave, T., & Schob, R. (2005). *Alleviating urban traffic congestion*. Cambridge, MA: MIT Press.

ARUP. (2011). *Analysis of renewable energy to inform UK investment*. Retrieved May 15, 2014, from http://www.arup.com/News/2011_06_June/10_Jun_11_DECC_Analysis_of_Renewable_Energy

Augé-Blum, I., Boussetta, K., Rivano, H., Stanica, R., & Valois, F. (2012). Capillary Networks: A Novel Networking Paradigm for Urban Environments. In Proceedings of UrbaNE. doi:10.1145/2413236.2413243

Australian Automobile Association. (2013). *Star rating, Australia's national network of highways, Australian Road Assessment Program*. Australia: Australian Automobile Association.

Australian Transport Council. (2011). *National road safety strategy 2011-2020*. Australia: Australian Transport Council.

AustRoads. (2002). *Guide to road safety part 6: Road Safety Audit*. Sydney, Australia: AustRoads.

Aydinalp, M., Ugursal, V. I., & Fung, A. (2002). Modeling of the appliance, lighting, and space cooling energy consumptions in the residential sector using neural network. *Applied Energy*, *72*(2), 87–110. doi:10.1016/S0306-2619(01)00049-6

Azkuna, I. (n.d.). *Smart Cities: International study on the situation of ICT, innovation and Knowledge in cities.* Retrieved June 16, 2014, from http://www.cities-local-governments.org/committees/cdc/Upload/formations/smartcitiesstudy_en.pdf

Bahu, J.-M., Koch, A., Kremers, E., & Murshed, S. M. (2013). Towards a spatial urban energy modelling approach. In *Proceedings of 3D GeoInfo Conference* (pp. 27-29).

Bai, F., Stancil, D. D., & Krishnan, H. (2010). Toward understanding characteristics of dedicated short range communications (DSRC) from a perspective of vehicular network engineers. In *Proceedings of ACM MobiCom*. doi:10.1145/1859995.1860033

Bairoch, P. (2013). *The Economic Development of the Third World Since 1900*. Routledge.

Bajardi, M. (2013). *Designing digital regions*. (Unpublished doctoral dissertation). University of Sannio, Italy.

Baker, H. M., Franz, L. S., & Sweigart, J. R. (1993). Coordinated transportation systems: An alternative approach to traditional independent systems. *European Journal of Operational Research*, *66*(3), 341–352. doi:10.1016/0377-2217(93)90222-9

Balram, S., & Dragicevic, S. (2005). Attitude towards Urban Green Spaces; Integrated Questionnaire Survey and Collaborative GIS Techniques to Improve Attitude Measurement. *Elsevier: Landscape and Urban Planning*, *71*(2-4), 147–162.

Barabasi, A. L. (2002). *Linked. The New Science of Networks*. Cambridge, MA: Perseus Publishing.

Barrett, M., & Spataru, C. (2011). DYNEMO: *Dynamic Energy Model, Model Documentation*. Retrieved from http://www.ucl.ac.uk/energymodels/models/dynemo

Barrett, M., & Spataru, C. (2012). *DEAM: Dynamic Energy Agents Model*. Retrieved from http://www.ucl.ac.uk/energy-models/models/deam

Barrett, M., & Spataru, C. (2015) DynEMo: A Dynamic Energy Model for the Exploration of Energy, Society and Environenment, UKSim 2015-17th International Conference on Mathematical/Analytical Modelling and Computer Simulation, Cambridge, March 2015

Barrett, M., & Spataru, C. (2013). Dynamic simulation of energy system. *Advanced Materials Research*, *622-623*, 1017–1021. doi:10.4028/www.scientific.net/AMR.622-623.1017

Barrett, M., & Spataru, C. (2013). Optimizing building energy systems and controls for energy and environment policy. In A. Håkansson, M. Höjer, R. J. Howlett, & L. C. Jain (Eds.), *Smart Innovation, Systems and Technologies, Sustainability in Energy and Buildings* (pp. 413–425). Berlin, Heidelberg: Springer-Verlag., Elsevier. doi:10.1007/978-3-642-36645-1_39

Barthel, D., Lampin, L., Augé-Blum, I., & Valois, F. (2012). Exploiting long-range opportunistic links to improve delivery, delay and energy consumption in Wireless Sensor Networks. In *Proceedings of IEEE MASS*.

Bartolo, M., & Mariani, I. (2014). *Game design*. Milan, IT: Pearson.

Bartone, C., Bernstein, J., Leitman, J., & Eigen, J. (1994). Toward Environmental Strategies for Cities: Policy Considerations for Urban Environmental Management in Developing Countries. Washington, DC: the World Bank.

Basciotti, D., & Schmidt, R.R. (2013). *Demand side management in District heating networks, Simulation case study on load shifting*.

BASE. (2006). *Public finance mechanisms to increase investment in energy efficiency. A report for policy makers and public finance agencies*. Retrieved May 15, 2014, from http://www.energy-base.org/wp-content/uploads/2013/11/SEFI-Public-Finance-Mechanisms-to-Increase-Investment-in-Energy-Efficiency.pdf

Batty, M. (1997). The Computable City. *International Planning Studies, 2*, 155-173. Retrieved from https://web.archive.org/web/19980124005925/http://www.geog.buffalo.edu/Geo666/batty/melbourne.html

Batty, M. (2008). *Cities as Complex Systems: Scaling, Interactions, Networks, Dynamics and Urban Morphologies*. CASA working papers series 131.

Batty, M. (2003). Planning support systems: technologies that are driving planning. In S. Geertman & J. Stillwell (Eds.), *Planning Support Systems in Practice*.

Batty, M. (2005). *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based*. Cambridge, MA: The MIT Press.

Batty, M. (2013). Big data, smart cities and city planning. *Dialogues in Human Geography*, *3*(3), 274–279. doi:10.1177/2043820613513390

Batty, M. (2013). *The New Science of Cities*. Cambridge: MIT Press.

Batty, M. (2014). *The Smart Cities Movement, forthcoming CASA working papers series*. London: UCL.

Batty, M., Axhausen, K., Fosca, G., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., & Portugali, Y. et al. (2012). Smart Cities of the Future. *The European Physical Journal. Special Topics*, *214*(1), 481–518. doi:10.1140/epjst/e2012-01703-3

Bauman, Z., & Lyon, D. (2013). *Liquid Surveillance: A Conversation*. Cambridge: Polity Press.

Bauwens, M. (2005). *The political economy of peer production*. Retrieved from http://www.ctheory.net/articles.aspx?id=499

Baycan-Levent, T., & Nijkamp, P. (2004). Planning and Management of Urban Green Spaces in Europe: Comparative Analysis. *Journal of Urban Planning and Development*, *135*(1), 1–12. doi:10.1061/(ASCE)0733-9488(2009)135:1(1)

Bayoumi, T., Dell'Ariccia, G., Habermeier, K. F., Mancini Griffoli, T., & Valencia, F. (2014). *Monetary Policy in the New Normal. Staff Discussion Notes, 14(3)*. International Monetary Fund.

Bazzan, A. L. (2009). Opportunities for multiagent systems and multiagent reinforcement learning in traffic control. *Autonomous Agents and Multi-Agent Systems*, *18*(3), 342–375. doi:10.1007/s10458-008-9062-9

Bazzanella, L., Roccasalva, G., & Valenti, S. (2013). *Phigital Public Space Approach: A Case Study in Volpiano*. Retrieved from http://www.mifav.uniroma2.it/inevent/events/pcst_sce_2013/docs/I_5.pdf. 2013.

Bazzi, A., Masini, B. M., & Andrisano, O. (2011). On the Frequent Acquisition of Small Data Through RACH in UMTS for ITS Applications. *IEEE Transactions on Vehicular Technology*, *60*(7), 2914–2926. doi:10.1109/TVT.2011.2160211

Becker, T., Nagel, C., & Kolbe, T. H. (2013). *Semantic 3D modeling of multi-utility networks in cities for analysis and 3D visualization. Progress and New Trends in 3D Geoinformation Sciences* (pp. 41–62). Berlin, Heidelberg: Springer Verlag. doi:10.1007/978-3-642-29793-9_3

Beer, A., & Jorgensen, A. (2003). New Approach in Europe. In *Decent Homes Decent Spaces*. Retrieved from http://www.neighbourhoodsgreen.org.uk/upload/public/documents/webpage/dhds%20reduced.pdf

Begg, I. (2002). *Urban Competitiveness: Policies for Dynamic Cities*. Bristol: Policy Press.

Belay, A. (2002). *Green Frame Development Study*. Ministry of Federal Affair AAIDPO.

Bell, D. (1974). *The coming of post-industrial society*. London: Heinemann.

Benevolo, L. (2011). *La fine della città*. Bari: Laterza.

Benkler, Y. (2006). *The Wealth of Networks: How Social Production Transforms Markets and Freedom. London*. New Haven: Yale University Press.

Benkler, Y., & Nissenbaum, H. (2006). Commons-based Peer Production and Virtue*. *Journal of Political Philosophy*, *14*(4), 394–419. doi:10.1111/j.1467-9760.2006.00235.x

Bensemann, T., & Kiesewetter, D. (2008). *Who has really paid for the Reconstruction of East Germany? Expected and Realized Returns on Real Estate Investments in East and West Germany in the 1990s. FEMM Working Papers 08007*. Otto-von-Guericke University Magdeburg, Faculty of Economics and Management.

Bernstein, M. S., Karger, D. R., Miller, R. C., & Brandt, J. (2012). *Analytic Methods for Optimizing Realtime Crowdsourcing*. Collective Intelligence.

Berry, C. R., & Glaeser, E. L. (2005). The divergence of human capital levels across cities. *Papers in Regional Science*, *84*(3), 407–444. doi:10.1111/j.1435-5957.2005.00047.x

Berst, J. (2013). *AT&T's smart city Solutions: Q&A with Reed Pangborn*. Retrieved June 16, 2014, from http://smartcitiescouncil.com/resources/atts-smart-city-solutions-qa-reed-pangborn

Bertoldi, P., Boza-Kiss, B., & Rezessy, S. (2007). *Latest development of energy service companies across Europe*. Retrieved from http://www.energy.eu/publications/LB-NA22927ENC_002.pdf

Bertoldi, P., Rezessy, S., & Vine, E. (2006). Energy service companies in European countries: Current status and a strategy to foster their development. *Energy Policy*, *34*(14), 1818–1832. doi:10.1016/j.enpol.2005.01.010

Betanews. (2012). *Twitter: 500 million accounts, billions of tweets, and less than one percent use their location*. Retrieved from http://betanews.com/2012/07/31/twitter-500-million-accounts-billions-of-tweets-and-less-than-one-percent-use-their-location/

Bettencourt, L. (2013). Four simple principles to plan the best city possible. *New Scientist*, *18*, 30–31. doi:10.1016/S0262-4079(13)62903-6

BetterVest. (2014). Retrieved May 15, 2014, from http://bettervest.de/

Beylot, A.-L., & Laboid, H. (2013). *Vehicular Networks: Models and Algorithms*. Wiley. doi:10.1002/9781118648759

Biderman, A. (2013). *Living in an Open-Air Computer*. Retrieved February 13, 2014, from http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2013/_html_en/interview-city-lab.html

Bigliani, R. (2011). *Smart Cities Update: IDC Smart Cities Index and Its Application in Spain*. International Data Corporation.

Bishop, I. (1998). Planning Support: Hardware and software in search of a system. *Computers, Environment and Urban Systems*, *22*(3), 189–202. doi:10.1016/S0198-9715(98)00047-7

Blomqvist, K. (2002). *Partnering in the Dynamic Environment: the Role of Trust in Asymmetric Technology Partnership Formation*. Retrieved from http://www.doria.fi/handle/10024/38551

Bluetooth SIG. (2009). *Specifications of the Bluetooth System, Covered Core Package: 3.0 + HS*.

Bluetooth SIG. (2013). *Specifications of the Bluetooth System, Covered Core Package: 4.1*.

BMW i. Malibu (Solar Carport Demo). (n.d.). *World Team Now*. Retrieved June 14, 2014, from http://worldteamnow.org/blog/2014/05/07/bmw-i-malibu-solar-carport-demo/

Bonvalet, C., Drosso, F., Benguigui, F., & Huynh, P.-M. (2007). *Vieillissement de la population et logement: Les strategies résidentielles et patrimoniales*. La Documentation Francaise.

Boomkens, R. (1998). *Een drempelwereld: Moderne ervaring en stedelijke open-baarheid*. Rotterdam: NAI Publisher.

Bordo, M. D., & Jeanne, O. (2002). *Monetary Policy and Asset Prices: Does "Benign Neglect" Make Sense?* International Monetary Fund.

Borja, J., & Muxi, Z. (2003). *El espacio público: ciudad y ciudadanía*. Barcelona: Electa.

Botsford, C., & Szczepanek, A. (2009). Fast charging vs. slow charging: Pros and cons for the new age of electric vehicles. EVS24, Stavanger, Norway.

Boulanger, A. G., Chu, A. C., Maxx, S., & Waltz, D. L. (2011). Vehicle electrification: Status and issues. *Proceedings of the IEEE*, *99*(6), 1116–1138. doi:10.1109/JPROC.2011.2112750

Bourdeau-Lepage, L., & Huriot, J.-M. (2006). *Megacities vs Global Cities. Development and Institutions*. Vienna, Austria: European Regional Science Association.

Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: A new system of cross-scale spatial indicators. *Building Research and Information*, *40*(5), 592–605. doi:10.1080/09613218.2012.703488

Bouw, M., de Lange, M. d., & de Waal, M. d. (2013). De hackable wereldstad. In j. Lekkerkerker, & S.d. Vries (Eds.), Ruimtevolk jaarboek 2013. nieuw kapitaal (pp. 163-167). Ruimtevolk.

Boyd, S., & Chan, R. (2002). *Placemaking: tools for community action*. Retrieved June 09, 2014, from http://www.sustainable.org/images/stories/pdf/Placemaking_v1.pdf

Braczyk, H., Cooke, P., & Heidenreich, M. (Eds.). (1998). *Regional Innovation Systems*. London: University College Press.

Braess, D., Nagurney, A., & Wakolbinger, T. (2005). On a paradox of traffic planning. *Transportation Science*, *39*(4), 446–450. doi:10.1287/trsc.1050.0127

Brandon, P. S., & Lombardi, P. (2011). *Evaluating sustainable development in the built environment*. Oxford: Wiley-Blackwell.

Brandstatt, C., Friedrichsen, N., Meyer, R., & Palovic, M. (2012). Roles and responsibilities in smart grids: A country comparison. In *Proceedings of IEEE International Conference on the European Energy Market* (pp. 1-8). doi:10.1109/EEM.2012.6254698

Brandt, N., Cambell, F., Deakin, M., Johansson, S., Malmström, M., Mulder, K., . . . Arman, L. (n.d.). *Participation, Indicators and Benchmarking. European Cities Moving Towards Climate Neutrality*. Retrieved November 29, 2014, from http://www.clue-project.eu/getfile.ashx?cid=69201&cc=5&refid=6

Brazil, W., & Caulfield, B. (2013). Does green make a difference: The potential role of smartphone technology in transport behaviour. *Transportation Research Part C, Emerging Technologies*, *37*, 93–101. doi:10.1016/j.trc.2013.09.016

Brinkerhoff, J. M. (2002). Assessing and improving partnership relationships and outcomes: A proposed framework. *Evaluation and Program Planning*, *25*(3), 215–231. doi:10.1016/S0149-7189(02)00017-4

Brooks, D. (2013). *The Philosophy of Data*. Retrieved from http://www.nytimes.com/2013/02/05/opinion/brooks-the-philosophy-of-data.html?_r=0

BSI. (n.d.). *Smart Cities*. Retrieved June 16, 2014, from http://shop.bsigroup.com/en/Browse-By-Subject/Smart-Cities/?t=r

Buratti, C. (2010). Performance analysis of IEEE 802.15.4 beacon-enabled mode. *IEEE Transactions on Vehicular Technology*, *59*(4), 2031–2045. doi:10.1109/TVT.2010.2040198

Bureau of Infrastructure. Transport and Regional Economics. (2014). Road Safety: Modeling a global phenomenon. Canberra, Australia: Bureau of Infrastructure, Transport and Regional Economics.

Burnham, A., Wang, W., & Wu, Y. (2006, November) Development and Application of GREET 2.7 - The Transportation Vehicle Cycle Model. Energy Systems Division, Argonne National Laboratory. Retrieved May 4, 2014, from http://www.transportation.anl.gov/pdfs/TA/378.pdf

Butner, R. S., Reid, D. J., Hoffman, M., Sullivan, G., & Blanchard, J.(2013). Non-Intrusive Load Monitoring Assessment: Literature Review and Laboratory Protocol. Retrieved from http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22635.pdf

Cabspotting. (2014). Retrieved from http://cabspotting.org/api

Cairney, T., & Speak, G. (2000). *Developing a "smart city": Understanding Information Technology Capacity and Establishing an Agenda for Change*. Retrieved November 30, 2014, from http://trevorcairney.com/wp-content/uploads/2012/11/IT_Audit.pdf

Calthorpe, P. (2011). *Urbanism in the age of climate change*. Washington: Island Press. doi:10.5822/978-1-61091-005-7

Caltrans. (2010). *Smart Mobility 2010*. Caltrans. Retrieved June 16, 2014 from http://www.dot.ca.gov/hq/tpp/offices/ocp/smf_files/Planning_Horizons_Presentation_070710/Intro_SMF_Chris_Ratekin_Plng_Hrzns_070710.pdf

Calvo, G. A., & Reinhart, C. M. (2002). Fear of Floating. *The Quarterly Journal of Economics*, *117*(2), 379–408. doi:10.1162/003355302753650274

Campbell, T. (2012). *Beyond Smart Cities: How cities network, learn and innovate*. New York, NY: Routledge.

Campolo, C., Molinaro, A., & Vinel, A. V. (2011). Understanding the performance of short-lived control broadcast packets in 802.11p/WAVE Vehicular networks. In *Proceedings of IEEE VNC*.

Campos Venuti, G. (2010). *Città senza cultura*. Bari: Laterza.

Capital, R. A. B. (2011). Retrieved from http://www.rabcap.com/home/?btnDisc1=Accept&pageLocation=cpi_a_rab

Caragliu, A., Del Bo, C., & Nijkamp, P. (2009). Smart cities in Europe. In *Proceedings of Central European Conference in Regional Science*.

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *16*(2), 65–82. doi:10.1080/10630732.2011.601117

Cardone, G., Cirri, A., Corradi, A., Foschini, L., & Maio, D. (2013a). MSF: An Efficient Mobile Phone Sensing Framework. *International Journal of Distributed Sensor Networks*, 2013.

Cardone, G., Foschini, L., Bellavista, P., Corradi, A., Borcea, C., Talasila, M., & Curtmola, R. (2013b). Fostering participaction in smart cities: A geo-social crowdsensing platform. *IEEE Communications Magazine*, *51*(6), 112–119. doi:10.1109/MCOM.2013.6525603

Carlsson, B. (2006). Internationalization of innovation systems: A survey of the literature. *Research Policy*, *35*(1), 56–57. doi:10.1016/j.respol.2005.08.003

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function, and composition of technological systems. *Journal of Evolutionary Economics*, *1*(2), 93–118. doi:10.1007/BF01224915

Carreras, I., Miorandi, D., Tamilin, A., Ssebaggala, E. R., & Conci, N. (2013). Matador: Mobile task detector for context-aware crowd-sensing campaigns. In *Proceedings of IEEE International Conference on Pervasive Computing and Communications Workshops* (pp. 212-217). doi:10.1109/PerComW.2013.6529484

Carrión, D., Lorenz, A., & Kolbe, T. H. (2010). Estimation of the energetic rehabilitation state of buildings for the city of Berlin using a 3D City Model represented in CityGML. *International Conference on 3D Geo-Information.*

Casey, T. (2014, January 9). Ford Packs More Solar Power Storage Punch Into MyEnergi Lifestyle. CleanTechnica. Retrieved June 15, 2014, from http://cleantechnica.com/2014/01/09/ford-adds-solar-power-storage-myenergi-lifestyle/

Cassandras, C. G., & Geng, Y. (2014). Optimal dynamic allocation and space reservation for electric vehicles at charging stations. In *Proceedings of 19th IFAC World Congress* (pp. 9611-9616).

Cassandras, C. G., & Lafortune, S. (2008). *Introduction to Discrete Event Systems*. New York, NY: Springer. doi:10.1007/978-0-387-68612-7

Cassandras, C. G., Wardi, Y., Melamed, B., Sun, G., & Panayiotou, C. G. (2002). Perturbation analysis for on-line control and optimization of stochastic fluid models. *IEEE Transactions on Automatic Control*, *47*(8), 1234–1248. doi:10.1109/TAC.2002.800739

Cassandras, C. G., Wardi, Y., Panayiotou, C. G., & Yao, C. (2010). Perturbation analysis and optimization of stochastic hybrid systems. *European Journal of Control*, *6*(6), 642–664. doi:10.3166/ejc.16.642-661

Castells, M. (1996). The Information Age: Economy, Society and Culture.: Vol. I. *The Rise of the Network Society*. Malden, MA; Oxford, UK: Blackwell.

Castells, M. (2004). *La Città delle Reti* [The Network Society]. Venice, Italy: Marsilio.

Catrinu, M. D. (2006). *Decision Aid for Planning Local Energy Systems, Application of Multi-Criteria Decision Analysis*. (Doctoral dissertation). Norwegian University of Science & Technology.

CDM. (2014). *Cisco Data Meter*. Retrieved from http://www.ciscovni.com/data-meter/

Ceder, A., Chowdhury, S., Taghipouran, N., & Olsen, J. (2013). Modelling public-transport users' behaviour at connection point. *Transport Policy*, *27*, 112–122. doi:10.1016/j.tranpol.2013.01.002

CEN/European Committee for Standardisation. (2012). *EN 15232 Energy performance of buildings - Impact of Building Automation*. Controls and Building Management.

CEN-CENELEC-ETSI Smart Grid Coordination Group. (2012). *Smart Grid Reference Architecture*.

CESBA. (2014). *Welcome to CESBA*. Retrieved November 28, 2014, from http://wiki.cesba.eu/wiki/Main_Page

CGAA. (2011). *Guide Line for Beautification and Park Development and Management Core Process*. Addis Ababa.

Chan, C. (2013). From open data to open innovation strategies: Creating e-services using open government data. In *Proceedings of Hawaii International Conference on System Sciences*. doi:10.1109/HICSS.2013.236

Chang, H.-J. (2010). Financial markets need to become less, not more, efficient. Chapter 22 in H.-J. Chang, 23 Things They Don't Tell You About Capitalism (pp. 230-241). London: Penguin.

Chen Lillemo, S. (2014). Measuring the effect of procrastination and environmental awareness on households' energy-saving behaviours: An empirical approach. *Energy Policy*, *66*, 249–256. doi:10.1016/j.enpol.2013.10.077

Chen, Z., Liu, N., & Xiao, X. (2013, May). Energy exchange model of PV-based battery switch stations based on battery swap service and power distribution. In Energytech, 2013 IEEE (pp. 1-6). IEEE. doi:10.1109/VPPC.2013.6671681

Chesbrough, H. W. (2003 Spring Issue). The Era of Open Innovation. *MIT Sloan Management Review*. Retrieved from http://sloanreview.mit.edu/article/the-era-of-open-innovation/

Chesbrough, H. (2003). The era of open innovation. *MIT Sloan Management Review*, *44*(3), 35–41.

Chesbrough, H. (2006). *Open innovation: The new imperative from creating and profiting from technology*. Boston: Harvard Business School Press.

Cheshire, J. A., & Manley, E. (2012). *Twitter Tongues*. Retrieved from http://twitter.mappinglondon.co.uk

Chin, H. C., & Haque, M. M. (2012). Effectiveness of red light cameras on the right-angle crash involvement of motorcycles. *Journal of Advanced Transportation*, *46*(1), 54–66. doi:10.1002/atr.145

Choi, W., Yoon, H., Kim, K., Chung, I., & Lee, S. (2002). A traffic light controlling flc considering the traffic congestion. In *Proceedings of the AFSS International Conference on Fuzzy Systems* (pp. 69-75). doi:10.1007/3-540-45631-7_10

Chou, J. (2011). *Intelligent transportation systems in Taiwan*. Taiwan: Ministry of Transportation and Communications.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, R., Mellouli, S., Nahon, K., & Scholl, H. J. et al. (2012). Understanding smart cities: An integrative framework. In *Proceedings of Hawaii International Conference on System Sciences* (pp. 2289-2297).

Chou, S., Lin, S., & Li, C. (2008). Dynamic parking negotiation and guidance using an agent-based platform. *Expert Systems with Applications*, *35*(3), 805–817. doi:10.1016/j.eswa.2007.07.042

Chua, B., & Brennan, J. (2004). Enhancing collaborative knowledge management systems designs. In *Proceedings European Conference on Knowledge Management* (pp. 171-179).

Cisco. (2013). *Global Mobile Data Traffic Forecast Update*.

Cisco. (n.d.). *CUD Thought Leadership - Cisco Consulting Thought Leadership*. Retrieved June 16, 2014, from http://www.cisco.com/web/about/ac79/ps/cud/thought_leadership.html

Cisco. (n.d.). *Internet of Everything*. Retrieved June 16, 2014, from http://www.cisco.com/web/about/ac79/innov/IoE.html

Cisco. (n.d.). *Smart+Connected Communities - Industry Solutions*. Retrieved June 16, 2014, from http://www.cisco.com/web/strategy/smart_connected_communities.html

CITA. (2007). *AUTOFORE - Study on the future options for roadworthiness enforcement in the European Union*. Belgium: Comité International De L'inspection Technique Automobile.

Citigroup. (2012). *Benchmarking global city competitiveness*. The Economist. Retrieved June 16, 2014, from http://www.citigroup.com/citi/citiforcities/pdfs/eiu_hotspots_2012.pdf

Cittalia (2009). *Le città mobili. Rapporto Cittalia 2009*. Pomezia, Italy: Cittalia.

City Climate Leadership Awards. (2014). *Milan: Area C: Fewer Cars, More Public Spaces, Better Life For All*. Retrieved July 29, 2014 from http://cityclimateleadershipawards.com/2014-project-milan-area-c/?utm_content=buffer0df65&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

City Indicators. (n.d.). *Global City Indicator Facility (GCIF) Indicators*. Retrieved June 15, 2014, from http://www.cityindicators.org

Clean Air Initiative for Asian Cities. (2006). *Sustainable urban transport in Asia - making the vision a reality.* Retrieved from http://pdf.wri.org/sustainable_urban_transport_asia.pdf

Cobb, J. (2014). Top 6 plug-in vehicle adopting countries. Retrieved from http://www.hybridcars.com/top-6-plug-in-car-adopting-countries/

Cohen, B. (2012). *What Exactly is A smart city?* Retrieved June 16, 2014, from http://www.fastcoexist.com/1680538/what-exactly-is-a-smart-city

Comune di Palermo. (2013). *Open data*. Retrieved March 13, 2014, from http://www.comune.palermo.it/opendata.php

Concilio, G., Molinari, F., & Puerari, E. (2014). Rethinking Activism: Living Labs and Urban Participation. Contribution presented at *the EURA 2014 Conference*. Paris, France.

Concilio, G., De Bonis, L., Marsh, J., & Trapani, F. (2011). Urban Smartness: Perspectives Arising in the Periphèria Project. *Journal of Knowledge Economy*, *4*(2), 205–216.

Concilio, G., Marsh, J., Molinari, F., & Rizzo, F. (2013). Human Smart Cities. A New Vision for Redesigning Urban Community and Citizen's Life. In *Proceedings of the 8th International Conference on Knowledge, Information and Creativity Support Systems*. Krakow, Poland.

Concilio, G., & Molinari, F. (2014). Urban Living Labs: Learning Environments for Collective Behavioural Change.*Proceedings of the IFKAD '14 Conference*. Matera, Italy.

Connected Living. (2014). *Smart Cities*. Retrieved June 16, 2014, from http://smartcitiesindex.gsma.com/indicators/

Connolly, D., Lund, H., Mathiesen, B. V., & Leahy, M. (2010). A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, *87*(4), 1059–1082. doi:10.1016/j.apenergy.2009.09.026

Cooke, R. (2014). *Crowdfunding is a financial lifeline for community energy*. Retrieved May 15, 2014, from http://trillionfund.com/crowdfunding-is-a-financial-lifeline-for-community-energy/

Copert (n.d.). Copert - The popular, straightforward and simple to use emissions calculator. Retrieved November, 30, 2014 from http://www.emisia.com/copert/

Couclelis, H. (1989). Geographically informed planning: requirements for planning relevant GIS. In *Proceedings of 36th North American Meeting of Regional Science Association*. Santa Barbara.

Croce, R. D. (2011). *Pension Funds Investment in Infrastructure: Policy Actions*. Working Papers on Finance, Insurance and Private Pensions 13. Paris, France: OECD Publishing.

Crosta, P. (2006). *Interazioni: pratiche, politiche e produzione di pubblico. Un percorso attraverso la letteratura, con attenzione al conflitto. DiAP WSs*. Milan: Politecnico di Milano.

DailyTech - Tesla Building Tech to Fully Charge EVs in Just 5 Minutes. (n.d.). *DailyTech - Tesla Building Tech to Fully Charge EVs in Just 5 Minutes*. Retrieved June 14, 2014, from http://www.dailytech.com/Tesla+Building+Tech+to+Fully+Charge+EVs+in+Just+5+Minutes/article31990.htm

Dameri, R. P., D'Auria, B., & Ricciardi, F. (2014). Knowledge and intellectual capital in Smart City. In *Proceedings of European Conference on Knowledge Management*.

Dameri, R. P., & Rosenthal-Sabroux, C. (2014). *Smart City – How to Create Public and Economic Value with High Technology in Urban Space*. Berlin, Germany: Springer.

DASH7 Alliance. (2013). *DASH7 Alliance mode draft 02 release: An advanced communication system for wide-area low-power wireless applications and active RFID*.

Davenport, T. H., & Prusak, L. (1998). *Working Knowledge: How Organizations Manage What They Know*. Cambridge, MA: Harvard University Press.

Davezies, L. (2012). *La crise qui vient: La nouvelle fracture territoriale*. Paris: Seuil.

Davis, M. (2006). *Planet of Slums*. New York: Verso.

De Filippi, P., & Tréguer, F. (2014). Expanding the Internet Commons: The Subversive Potential of Wireless Community Networks, *Journal of Peer Production*.

de Freitas Miranda, H., & Rodrigues da Silva, A. N. (2012). Benchmarking sustainable urban mobility: The case of Curitiba, Brazil. *Transport Policy*, *21*, 141–151. doi:10.1016/j.tranpol.2012.03.009

de Lange, M., & de Waal, M. (2013). Owning the city: New media and citizen engagement in urban design. *First Monday*, *18*(11). doi:10.5210/fm.v18i11.4954

De Reuveur, G. A. (2009). *Governing mobile service innovation in co-evolving value networks.* Retrieved from http://repository.tudelft.nl/view/ir/uuid:e9e31abe-440b-4440-a5bb-f6760251601f/

de Roo, G., Visser, J., & Zuidema, C. (2012). *Smart Methods for Environmental Externalities – Urban Planning, Environmental Health and Hygiene in the Netherlands*. Farnham, United Kingdom: Ashgate.

de Waal, M. (2012). The ideas and ideals in urban media. In M. Foth (Ed.), *From social butterfly to engaged citizen*. Cambridge, MA: MIT Press.

de Waal, M., & Melis, G. (2015). Urban Living Labs & City-making: Open innovation and urban design. In E. Almirall & B. Cohen (Eds.), *Open Innovation as a driver for Smart Cities*. Netherlands: Springer.

Deakin, M., & Al Waer, H. (2011). From intelligent to smart cities. *Intelligent Building international, 2(3)*, 140-152.

Deakin, M. (2011). The embedded intelligence of smart cities. *International Journal of Intelligent Buildings*, *3*(2), 189–197. doi:10.1080/17508975.2011.579340

Deakin, M. (2012a). Intelligent cities as smart providers: CoPs as organizations for developing integrated models of eGovernment Services. *Innovation: The Journal of Social Research*, *23*(2), 115–135.

Deakin, M. (2012b). SCRAN: Assembling a Community of Practice for Standardizing the Transformation of eGovernment Services. In S. Aikins (Ed.), *Managing E-Government Projects: Concepts, Issues and Best Practices*. Hershey, PA: ICI Publisher.

Deakin, M. (2013a). Introduction (to smart cities). In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M. (2013b). The embedded intelligence of smart cities. In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M. (Ed.). (2013). *Smart Cities. Governing, modelling and analysing the transition*. London, New York: Routledge.

Deakin, M., & Allwinkle, S. (2007). Urban regeneration and sustainable communities: The role networks, innovation and creativity in building successful partnerships. *Journal of Urban Technology*, *14*(1), 77–91. doi:10.1080/10630730701260118

Deakin, M., & Cruickshank, P. (2013). SCRAN: the network. In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M., & Leydesdorff, L. (2013). The triple helix of smart cities: a neo-evolutionary perspective. In M. Deakin (Ed.), *Smart Cities: Governing, Modelling and Analysing the Transition*. Oxon: Routledge.

Deakin, M., & Reid, A. (2014). Sustainable urban development: Use of the environmental assessment methods. *Sustainable Cities and Society*, *10*, 39–48. doi:10.1016/j.scs.2013.04.002

Deakin, M., Reid, A., & Campbell, F. (2013). Demonstrating How Urban Morphology Matters: Reaching Beyond the Geometry of Building Design, Construction Systems and Occupational Behaviours and Towards Broader Context-Specific Transformations. *Environmental Management and Sustainable Development*, *2*(2), 101–121. doi:10.5296/emsd.v2i2.4307

DECC. (2014). *DECC Statistics: Renewable Energy Trends*. Retrieved from https://www.gov.uk/government/publications/energy-trends-section-6-renewables

Deng, F., Jordan, P., & Goodge, M. (2012). *Reducing traffic accidents in China: strengthening the use of road safety audits. China Transport Topics, 07*. Washington, DC: World Bank.

Dernbach, S., & Das, B. (2012). Simple and Complex Activity Recognition through Smart Phones. In *Proceedings of International Conference on Intelligent Environments* (pp. 214-221). doi:10.1109/IE.2012.39

DeSchutter, B. (1999). Optimal traffic light control for a single intersection. In *Proceedings of the American Control Conference* (pp. 2195-2199).

Dhameja, S. (2001). *Electric vehicle battery systems*. Newnes.

Di Felice, M., Ghandour, A. J., Artail, H., & Bononi, L. (2012). On the impact of multi-channel technology on safety-message delivery in IEEE 802.11p/1609.4 vehicular networks. In *Proceedings of IEEE ICCCN*.

Dickinson, J. L., Crain, R. L., Reeve, H. K., & Schuldt, J. P. (2013). Can evolutionary design of social networks make it easier to be 'green'? *Trends in Ecology & Evolution*, *28*(9), 561–569. doi:10.1016/j.tree.2013.05.011 PMID:23787089

DieselNet. (2007). *On-road vehicles emission standards in Japan*. Canada: Ecopoint Inc.

Dobbs, R., Smit, S., Remes, J., Manyika, J., Roxburgh, C., & Restrepo, A. (2011). *Urban world: Mapping the economic power of cities*. McKinsey Global Institute.

Dong, C. (2004). Area traffic signal timing optimization based on chaotic and genetic algorithm approach. *Computer Engineering and Applications*, *40*(29), 32–34.

Dong, C. (2006). Chaos-particle swarm optimization algorithm and its application to urban traffic control. *International Journal of Computer Science and Network Security*, *61*(1), 97–101.

Dong, C., Liu, Z., & Qiu, Z. (2005). Urban traffic signal timing optimization based on multi-layer chaos neural networks involving feedback. In *Proceedings of the First International Conference on Natural Computation* (pp. 340-344). doi:10.1007/11539087_41

Dornbusch, R., & Wolf, H. C. (1994). East German Economic Reconstruction. In O. J. Blanchard, K. A. Froot, & J. D. Sachs, The Transition in Eastern Europe, Volume 1 (pp. 155-190). University of Chicago Press.

Dowell, M., & Sung Ho, R. (2008). Aging Baby Boomers and the Generational Housing Bubble. *Journal of the American Planning Association*, *74*(1), 17–33. doi:10.1080/01944360701802006

Dressler, F., Hartenstein, H., Altintas, O., & Tonguz, O. K. (2014). Inter-vehicle communication-Quo Vadis. *IEEE Communications Magazine*, *52*(6), 170–177. doi:10.1109/MCOM.2014.6829960

Dujardin, Y., Boillot, F., Vanderpooten, D., & Vinant, P. (2011). Multiobjective and multimodal adaptive traffic light control on single junctions. In *Proceedings of the IEEE International Conference on Intelligent Transportation Systems* (pp. 1361-1368). doi:10.1109/ITSC.2011.6082977

Dutta, P. (2013, July). Use of inductive power transfer sharing to increase the driving range of electric vehicles. In *Power and Energy Society General Meeting (PES), 2013 IEEE* (pp. 1-5). IEEE. doi:10.1109/PESMG.2013.6672635

Dutta, P. (2014, July) Charge Sharing Model using Inductive Power Transfer to Increase Feasibility of Electric Vehicle Taxi Fleets. In *Power and Energy Society General Meeting (PES), 2014*. IEEE. doi:10.1109/PESGM.2014.6939294

Eberle, U., & von Helmolt, R. (2010). Sustainable transportation based on electric vehicle concepts: A brief overview. *Energy & Environmental Science*, *3*(6), 689–699. doi:10.1039/c001674h

Economist. (2004). *The Economist Intelligence Unit's quality-of-life index*. The Economist. Retrieved June 16, 2014, from http://www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf

Educnet. (2006). *Information system definition*. Retrieved from http://www2.educnet.education.fr/sections/superieur/glossaire/2006

Eichengreen, B. (1991, January). Is Europe an Optimum Currency Area? Working Paper 3579. The National Bureau of Economic Research.

Eichengreen, B. (2013). *Does the Fed Care About the Rest of the World?* The National Bureau for Economic Research.

Eichengreen, B. (2014). *The Dollar and the Damage Done*. Project Syndicate.

Eicker, U. (2006). System Management via Building and Supply System Simulation [Betriebsführung mittels Gebäude- und Anlagensimulation]. In *Proceedings of Workshop Concepts for Optimised Building Operation [Konzepte zur optimierten Betriebsführung von Gebäuden], Frankfurt*.

Elfkrink, W. (2012). Foreword. In Campbell, T. Beyond Smart City: How cities network, learn and innovate. New York, NY: Routledge.

Ellabban, O., Haitham, A.-R., & Frede, B. (●●●). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable & Sustainable Energy Reviews*, *39*, 748–764.

Ellis, R., Fackrell, C., Gordon, T., Lamb, P., Morris, J. E., & Kawasaki, C. (2013, August). Battery recharging and testing swap stations. In *Technologies for Sustainability (SusTech), 2013 1st IEEE Conference on* (pp. 208-211). IEEE. doi:10.1109/SusTech.2013.6617322

Ely, M., & Brick, E. (2012). Bicycle renaissance in a shared way. *Journeys*.

Enbysk, L. (2013). *Smart cities: Why it's location, location (and communication)*. Retrieved June 16, 2014, from http://smartcitiescouncil.com/article/smart-cities-why-its-location-location-and-communication

Energy Charter Secretariat. (2003). *Third party financing: Achieving its potential*. Retrieved from http://www.encharter.org/index.php?id=172&L=0

Energy Efficiency Financial Institution Group. (2014). Retrieved from http://www.endsreport.com/43517/european-commission-energy-efficiency-financial-institutions-group-report-on-how-to-drive-new-finance-for-energy-efficiency-investments

Ericsson. (2012). *Networked Society: Triple-bottom-line effects of accelerated ICT maturity in cities worldwide*. Retrieved June 16, 2014, from http://www.ericsson.com/res/docs/2012/networked-society-city-index-report-part-1.pdf and from http://www.ericsson.com/res/docs/2012/networked-society-city-index-report-part-2.pdf

Ericsson. (2014). *Networked Society*. Retrieved June 16, 2014, from http://www.ericsson.com/thinkingahead/networked_society

Ester, M., Kriegel, H.-P., Sander, J., & Xu, X. (1996). A density-based algorithm for discovering clusters in large spatial databases with noise. In *Proceedings of 2nd International Conference on Knowledge Discovery and Data Mining* (pp. 226-231).

Esty, D., Kim, C., Srebotnjak, T., Levy, M., Sherbinin, A., & Mara, V. (2008). *2008 Environmental Performance Index*. New Haven: Yale Center for Environmental Law and Policy.

ETSI TR 101 994-1. (2004). *Short Range Devices (SRD); Technical Characteristics for SRD Equipment using Ultra Wide Band Technology (UWB); Part 1: Communications Applications*.

ETSI TR 103 055-1.1.1. (2011). *Electromagnetic compatibility and Radio spectrum Matters (ERM) - System Reference document (SRdoc): Spectrum Requirements for Short Range Device, Metropolitan Mesh Machine Networks (M3N) and Smart Metering (SM) applications.*

Etzkowitz, H. (2008). *The Triple Helix: University-Industry-Government Innovation in Action*. London: Routledge. doi:10.4324/9780203929605

Etzkowitz, H., & Leydesdorff, L. (1998). The Endless Transition: A "Triple Helix" of University-Industry-Government Relations, Introduction to a Theme Issue. *Minerva*, *36*(3), 203–208. doi:10.1023/A:1004348123030

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy*, *29*(2), 109–123. doi:10.1016/S0048-7333(99)00055-4

Etzkowitz, H., & Leydesdorff, L. (2002). *Universities and the Global Knowledge Economy NIP: A Triple Helix of University-Industry Relations*. Continuum International Publishing Group Ltd.

European Central Bank. (2009). *Housing Wealth and Private Consumption in the EURO Area* (pp. 59–71). ECB Monthly Bulletin.

European Commission. (2007). *Integrated Urban Environmental Management: Guidance in Relation to the Thematic Strategy of Urban Environmental Management*. Retrieved from http://ec.europa.eu/environment/urban/pdf/iem.pdf

European Commission. (2009). *Living Labs for user-driven open innovation: An overview of the Living Labs methodology, activities and achievements*. Retrieved November, 30, 2014, from http://www.eurosportello.eu/sites/default/files/Living%20Lab%20brochure_jan09_en_0.pdf

European Commission. (2013). Renewable Energy Progress Report. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0175&from=EN European Commission. (2014). *Financial Instruments in Cohesion Policy 2014-2020*. Retrieved from http://ec.europa.eu/regional_policy/thefunds/funding/index_en.cfm

European Commission. (2014). *EU action on climate*. Retrieved from http://ec.europa.eu/clima/policies/brief/eu/index_en.htm

European Commission. (2014). *Guidance on Community-Led Local Development for Local Actors*. Retrieved from http://ec.europa.eu/regional_policy/sources/docgener/informat/2014/guidance_clld_local_actors.pdf

European Commission. (2014). *Mapping Smart Cities in the EU*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

European Commission. (n.d.) *Leader Tool-Kit*. Retrieved from http://enrd.ec.europa.eu/enrd-static/leader/leader/leader-tool-kit/the-leader-approach/en/the-leader-approach_en.html

European Investment Bank. (2007). *Investment Facility. EIB, Luxembourg European Investment Bank. (2011). The ELENA Facility. EIB, Luxembourg European Investment Bank. (2013). Review of the European PPP Market*. Luxembourg: EPEC.

European Parliament. (2006). Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services. Official Journal of the European Union, 64-85.

European Renewable Energy Council. (2014). Retrieved from http://www.erec.org/

Eurostat. (2014a). *Eurostat - nrg_100a: Supply, transformation, consumption - all products annual data.* Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en

Eurostat. (2014b). *Eurostat - nrg_ind_335a - Share of energy from renewable sources*. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_335a&lang=en

Evora, J., Kremers, E., Cueva, S. M., Hernandez, M., Hernandez, J. J., & Viejo, P. (2011). Agent-based modelling of electrical load at household level. In *Proceedings of Workshop on Complex Systems Modelling and Simulation.*

Ezell, S. (2010). *Explaining international IT application leadership: Intelligent transportation systems*. Washington, DC: The Information Technology & Innovation Foundation.

Ezkowitz, H., & Zhou, C. (2006). Triple Helix twins: Innovation and sustainability. *Science & Public Policy*, *33*(1), 77–83. doi:10.3152/147154306781779154

Faraji-Zonooz, M. R., Nopiah, Z. M., Yusof, A. M., & Sopian, K. (2009). A review of MARKAL energy modeling. *European Journal of Scientific Research*, *26*(3), 352–361.

FDRE. (1995). The Constitution of the Federal Democratic Republic of Ethiopia. *Proclamation No*, *1/1995*, 1–38.

FDRE. (1997). *The Environmental Policy of Ethiopia* (p. 15). Protection Authority.

FDRE. (2008). Urban Planning. Proclamation No. 574/2008c (pp. 4067-4085).

Fehske, A., Richter, F., & Fettweis, G. (2009). Energy efficiency improvements through micro sites in cellular mobile radio networks. In *Proceedings of IEEE GLOBECOM Workshops*. doi:10.1109/GLOCOMW.2009.5360741

Fernback, J. (2010). Urban planning unplugged: How wireless mobile technology is influencing design elements in seven major US cities. *Communications of the Association for Information Systems*, *27*(November), 651–664.

Ferro, E., Caroleo, B., Leo, M., Osella, M., & Pautasso, E. (2013). The role of ICT in smart cities governance. In *Proceedings of Conference Democracy and Open Government*.

Filsecker, M., & Hickey, D. T. (2014). A multilevel analysis of the effects of external rewards on elementary students' motivation, engagement and learning in an educational game. *Computers & Education*, *75*, 136–148. doi:10.1016/j.compedu.2014.02.008

Finance Working Group for Smart Cities. (2014). Retrieved from http://eu-smartcities.eu/groups

Findler, N. V., & Strapp, J. (1992). A distributed approach to optimized control of street traffic signals. *Journal of Transportation Engineering*, *118*(1), 99–110. doi:10.1061/(ASCE)0733-947X(1992)118:1(99)

Findler, N. V., Surender, S., & Catrava, S. (1997). On-line decision about permitted/protected left-hand turns in distributed traffic signal control. *Engineering Applications of Artificial Intelligence*, 10.

Fleck, J. L., & Cassandras, C. G. (2014). Infinitesimal perturbation analysis for quasi-dynamic traffic light controllers. In *Proceedings of the 12th International Workshop on Discrete Event Systems* (pp. 235-240).

Flood, J. (2011). *The Fires: How a Computer Formula, Big Ideas, and the Best of Intentions Burned Down New York City and Determined the Future of Cities*. New York, NY: Riverhead Trade.

Florida, R. (2002). The economic geography of talent. *Annals of the Association of American Geographers*, *92*(4), 743–755. doi:10.1111/1467-8306.00314

Florida, R. (2004). *The Rise of the Creative Class: A Toolkit for Urban Innovators*. New York: Basic Books.

Fogg, B. J. (1998). Persuasive computers: perspectives and research directions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 225-232).

Fogg, B. J. (2002). *Persuasive technology: using computers to change what we think and do*. Burlington, MA: Morgan Kaufmann Publishers.

Fogg, B. J. (2009). A behavior model for persuasive design. In *Proceedings of 4th International Conference on Persuasive Technology* (pp. 1-7).

Foo, T. S. (2000). An advanced demand management instrument in urban transport: Electronic road pricing in Singapore. *Cities (London, England)*, *17*(1), 33–45. doi:10.1016/S0264-2751(99)00050-5

Foth, M., Choi, J. H., & Satchell, C. (2011). Urban Informatics.*InProceedings of the ACM Conference on Computer Supported Cooperative Work* (pp. 1-8).

Foxon, T. J., Leach, M., Butler, D., Dawes, J., Hutchinson, D., Pearson, P., & Rose, D. (1999). Useful Indicators of urban sustainability: Some methodological issues. *Local Environment*, *4*(2), 137–149. doi:10.1080/13549839908725589

Fujitsu. (2014). *smart city*. Retrieved June 16, 2014, from http://jp.fujitsu.com/about/csr/feature/2012/smartcity/

Fu, M. C., & Howell, W. C. (2003). Application of perturbation analysis to traffic light signal timing. In *Proceedings of 42nd IEEE Conference on Decision and Control* (4837-4840). doi:10.1109/CDC.2003.1272360

Fusaro, P., & Vasey, G. (2006). *Energy And Environmental Hedge Funds: The New Investment Paradigm*. New Jersey: Wiley Finance.

Gaillard, G., Barthel, D., Theoleyre, F., & Valois, F. (2014). Service Level Agreements for Wireless Sensor Networks: a WSN Operator's Point of View. In *Proceedings of IEEE/IFIP NOMS*. doi:10.1109/NOMS.2014.6838261

Gallo, L., & Härri, J. (2013). A LTE-Direct Broadcast Mechanism for Periodic Vehicular Safety Communications. In *Proceedings of IEEE VNC*. doi:10.1109/VNC.2013.6737604

Gal-Tzur, A., Grant-Muller, S. M., Minkov, S., & Nocera, S. (2014). The Impact of Social Media Usage on Transport Policy: Issues, Challenges and Recommendations. *Procedia: Social and Behavioral Sciences*, *111*, 937–946. doi:10.1016/j.sbspro.2014.01.128

Garreau, J. (1991). *Edge City: Life on the New Frontier*. Anchor Books.

Gartner, N. H., Pooran, F. J., & Andrews, C. M. (2002). Implementation and field testing of the OPAC adaptive control strategy in RT-TRACS. *Journal of the Transportation Research Board*, 148-156.

Gatautis, R., & Vitkauskaite, E. (2014). Crowdsourcing Application in Marketing Activities. *Procedia: Social and Behavioral Sciences*, *110*, 1243–1250. doi:10.1016/j.sbspro.2013.12.971

Gatersleben, B., Murtagh, N., & White, E. (2013). Hoody, goody or buddy? How travel mode affects social perceptions in urban neighborhoods. *Transportation Research Part F: Traffic Psychology and Behaviour*, *21*, 219–230. doi:10.1016/j.trf.2013.09.005

GEA. (2012). *Toward a Sustainable Future*. Cambridge, UK: Cambridge University Press.

Geertman, S. (2002). Participatory planning and GIS: A PSS to bridge the gap. *Environment and Planning. B, Planning & Design*, *29*(1), 21–35. doi:10.1068/b2760

Geertman, S., & Stillwell, J. (Eds.). (2003). *Planning Support Systems in Practice*. Berlin, Germany: Springer. doi:10.1007/978-3-540-24795-1

Geng, Y., & Cassandras, C. G. (2014). Multi-intersection traffic light control with blocking. *Journal of Discrete Event Dynamic Systems*. Preprint at http://link.springer.com/article/10.1007/s10626-013-0176-0#page-1

Geng, Y., & Cassandras, C. G. (2012a). Multi-intersection traffic light control using infinitesimal perturbation analysis. In *Proceedings of 11th International Workshop on Discrete Event Systems* (pp. 104-109).

Geng, Y., & Cassandras, C. G. (2012b). Traffic light control using infinitesimal perturbation analysis. In *Proceedings of 51st IEEE Conference on Decision and Control* (pp. 7001-7006). doi:10.1109/CDC.2012.6426611

Geng, Y., & Cassandras, C. G. (2013). A new "Smart Parking" system based on resource allocation and reservations. *IEEE Transactions on Intelligent Transportation Systems*, *14*(3), 1129–1139. doi:10.1109/TITS.2013.2252428

Gesi. (2012). *SMARTer2020*. Retrieved June 16, 2014, from http://gesi.org/SMARTer2020

Gibson, D. V., Kozmetsky, G., & Smilor, R. W. (Eds.). (1992). *The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Networks*. New York, NY: Rowman & Littlefield.

Giffinger, R. (2007): *Smart cities, Ranking of European medium-sized cities*. Retrieved from http://www.smart-cities.eu/download/smart_cities_final_report.pdf

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., & Meijers, E. (2007). *Smart Cities - Ranking of European medium-sized cities*. Retrieved from http://www.smart-cities.eu/download/smart_cities_final_report.pdf

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., & Meijers, E. (2007). *Smart cities. Ranking of European medium-sized cities*. Retrieved November, 30, 2014, from http://www.smartcities.eu/download/smart_cities_final_report.pdf

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., & Meijers, E. (2007). *Smart cities. Ranking of European medium-sized cities. Vienna: Centre of Regional Science, Vienna UT*. Retrieved March 13, 2013, from www.smartcities.eu

Giffinger, R. (2007). *Smart cities Ranking of European medium-sized cities*. Vienna, UT: Centre of Regional Science.

Gil, B. (2011). Trends and issues of PPP models in transport focused on South Korea and the UK. In *Proceedings of symposium of Public Private Partnerships in Transport: Trends & Theory, Research Roadmap*. Lisbon, Portugal.

Girardin, L., Marechal, F., Dubuis, M., Calame-Darbellay, N., & Favrat, D. (2010). EnerGis: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas. *Energy*, *35*(2), 830–840. doi:10.1016/j.energy.2009.08.018

Glaeser, E. (2008). *Cities, Agglomeration and Spatial Equilibrium*. Oxford University Press.

Glaeser, E. (2011). *The Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier and Happier*. New York: Penguin Group Inc.

Glaeser, E. L., & Berry, C. R. (2006). *Why are smart places getting smarter?* Cambridge, MA: Taubman Centre.

Global Compact. (n.d.). *The Cities Programme*. Retrieved June 15, 2014, from http://citiesprogramme.com

Gnüchtel, S., & Groß, S. (2010). Free optimization tools for district heating systems. In *Proceedings of International Symposium on District Heating and Cooling*.

Goetzmann, W. N., & Newman, F. (2010). *Securitization in the 1920's*. The National Bureau of Economic Research. doi:10.3386/w15650

Golle, P., Leyton-Brown, K., Mironov, I., & Lillibridge, M. (2001). Incentives for sharing in peer-to-peer networks. *Electronic Commerce*, *2232*, 75–87.

González, A., Donnelly, A., Jones, M., Chrysoulakis, N., & Lopes, M. (2013). A decision-support system for sustainable urban metabolism in Europe. *Environmental Impact Assessment Review*, *38*, 109–119. doi:10.1016/j.eiar.2012.06.007

Goodwin, N. R. (2003). *Five Kinds of Capital: Useful Concepts for Sustainable Development*. Global Development and Environment Institute.

Gordon, T., Karacapilidis, N., Voss, H., & Zauke, A. (1997). Computer-mediated cooperative spatial planning. In H. Timmermans (Ed.), *Decision support systems in urban planning* (pp. 299–309). E & FN Spon.

Government of Ireland. (2008). *Building Ireland's Smart Economy. A Framework for Sustainable Economic Renewal*. Dublin. Green Capital Index. (n.d). *European Green Capital: Evaluation Process*. Retrieved June 15, 2014, from http://ec.europa.eu/environment/europeangreencapital/applying-for-the-award/evaluation-process/index.html#sthash.QXukMUww.dpuf

Graham, S., & Crang, M. (2007). Sentient cities: Ambient intelligence and the politics of urban space. *Information Communication and Society*, *10*(6), 789–817. doi:10.1080/13691180701750991

Greater London Authority. (2011). *The London Plan: Spatial development strategy for Greater London*. London: GLA.

Green City Index. (n.d.). Retrieved June 16, 2014, from www.siemens.com/entry/cc/en/greencityindex.htm

Greenfield, A. (2013). *Against the smart city*. New York: Do projects.

Greenfield, A. (2013). *Against the Smart City. Amazon Media Kindle*. New York, NY: Do Projects.

Griffith, E. (2000). Pointing the way. *ITS International, 72*.

Grundstein, M., Rosenthal-Sabroux, C., & Pachulski, A. (2003). Reinforcing decision aid by capitalizing on company's knowledge: Future prospects. *European Journal of Operational Research*, *145*(2), 256–272. doi:10.1016/S0377-2217(02)00533-7

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2012). Smart Grid and Smart Homes: Key Players and Pilot Projects. *IEE Industrial Electronics Magazine*, *6*(4), 18–34. doi:10.1109/MIE.2012.2207489

Haile, F. (2003). Environmental Planning in the Context of Urban Planning in Ethiopia: Existing Practice and Prospects. In *Proceedings of National Conference of Urban Planning and Related Issues* (pp.113-115). National Urban Planning Institute.

Haklay, M. (2010). Geographical Citizen Science – Clash of Cultures and New Opportunities. In *Proceedings of Workshop on the Role of Volunteered Geographic Information in Advancing Science*. Retrieved from http://web.ornl.gov/sci/gist/workshops/2010/papers/Haklay.pdf

Han, B., Hui, P., Kumar, V., Marathe, M., Pei, G., & Srinivasan, A. (2010). Cellular Traffic Offloading through Opportunistic Communications: A Case Study. In *Proceedings of ACM CHANTS*. doi:10.1145/1859934.1859943

Haque, M. M., Chin, H. C., & Debnath, A. K. (2013). Sustainable, safe, smart - three key elements of Singapore's evolving transport policies. *Transport Policy*, *27*(0), 20–31. doi:10.1016/j.tranpol.2012.11.017

Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*(3859), 1243–1248. doi:10.1126/science.162.3859.1243 PMID:5699198

Harris, A. (2009). Charge of the electric car (electric vehicles). *Engineering & Technology*, *4*(10), 52–53. doi:10.1049/et.2009.1009

Harris, B., & Batty, M. (1993). Locational models, geographical information and planning support systems. *Journal of Planning Education and Research*, *12*(3), 84–98. doi:10.1177/0739456X9301200302

Harrison, C., & Abbott-Donnelly, I. (2011). A Theory of Smart Cities, Annual Meeting of the ISSS. Retrieved from http://journals.isss.org/index.php/proceedings55th/article/viewFile/1703/572

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. *IBM Journal of Research and Development*, *54*(4), 1–16. doi:10.1147/JRD.2010.2048257

Hartenstein, H., & Laberteaux, K. (2008). A tutorial survey on vehicular ad hoc networks. *IEEE Communications Magazine*, *46*(6), 164–171. doi:10.1109/MCOM.2008.4539481

Hartenstein, H., & Laberteaux, K. (2010). *VANET - Vehicular Applications and Inter-Networking Technologies*. Wiley.

Hart, G. W. (1992). Nonintrusive appliance load monitoring. *Proceedings of the IEEE*, *80*(12), 1870–1891. doi:10.1109/5.192069

Harvey, D. (2010). *The Enigma of Capital and the Crises of Capitalism*. Oxford University Press.

Harvey, D. (2012). *Rebel Cities: From the Right to the City to the Urban Revolution*. New York: Verso.

Hasan, S., Ben-David, Y., Fanti, G., Brewer, E., & Shenker, S. (2013). Building Dissent Networks: Towards Effective Countermeasures against Large-Scale Communications Blackouts. In *Proceedings of Workshop on Free and Open Communications on the Internet*.

He, H. (2013). *Passenger car fuel-efficiency 2020-2025: comparing stringency and technology feasibility of the Chinese and US standards*. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_PVfe-feasibility_201308.pdf

Head, L., Ciarallo, F., & Kaduwela, D. L. (1996). *A perturbation analysis approach to traffic signal optimization*. Paper presented at the 1996 INFORMS National Meeting.

Healy, K., & Schussman, A. (2003). *The ecology of open-source software development*. Retrieved November, 30, 2014, from http://kieranhealy.org/files/drafts/oss-activity.pdf

Heeter, J., & Mclaren, J. (2012). *Innovations in Voluntary Renewable Energy Procurement: Methods for Expanding Access and Lowering Cost for Communities, Governments, and Businesses Acknowledgments*. Retrieved from http://renewablemarketers.org/pdf/NREL_2012_innovation.pdf

Hellström, R. M., McCormick, K., Nilsson, E., & Arsenault, N. (2012). Advancing Sustainable Urban Transformation through Living Labs: Looking to the Öresund Region. In *Proceedings of the International Conference on Sustainability Transitions*. Copenhagen, Denmark.

Hemment, D., & Townsend, A. (2013). *Smart citizens*. Retrieved November 30, 2014, from http://futureeverything.org/wp-content/uploads/2014/03/smartcitizens1.pdf

Henning, T., Mohammed, D. E., & Oh, J. E. (2011). *A framework for urban transport benchmarking*. Retrieved from http://www.utbenchmark.in/img/RefDocuments/Home-Ref-1-3-1.pdf

Henry, J. J., & Farges, J. (1990). *PRODYN control, computers, communications in transportation*. Oxford, UK: Pergamon Press.

Henry, J., Farges, J., & Gallego, J. (1998). Neuro-fuzzy techniques for traffic control. *Control Engineering Practice*, *6*(6), 755–761. doi:10.1016/S0967-0661(98)00081-1

Highway Industry Development Organization. (2004). *ITS handbook, Japan: 2003-2004*. Japan: Highway Industry Development Organization.

Hirota, K., & Minato, K. (2001). *Inspection and maintenance system in Japan*. In *Proceedings of workshop on Inspection and Maintenance Policy in Asia*. Bangkok, Thailand.

Hocking, D. (2010). *In-vehicle telematics: Informing a National Strategy*.

Hodel, T. B., & Cong, S. (2003). Parking space optimization services, a uniformed web application architecture. In *Proceedings of Intelligent Transport Systems and Services,ITS World Congress* (pp. 16-20).

Hollands, R. (2008). Will the real smart city please stand up? *City*, *12*(3), 302–320. doi:10.1080/13604810802479126

Hollborn, S. (2002). *Intelligent Transport Systems (ITS) in Japan*. Japan: Institute of Industrial Science, University of Tokyo.

Holleczek, T., Yu, L., Lee, J., Senn, O., Kloeckl, K., Ratti, C., & Jaillet, P. (2013). Digital breadcrumbs: Detecting urban mobility patterns and transport mode choices from cellphone networks.

Holma, H., & Toskala, A. (2001). *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications*. Wiley.

Hopkins, L. (1999). Structure of a planning support system for urban development. *Environment and Planning. B, Planning & Design*, *26*(3), 333–343. doi:10.1068/b260333

Hopper, N., Goldman, C., Gilligan, D., Singer, T., & Birr, D. (2007). *A Survey of the U.S. ESCO Industry: Market Growth and Development from 2000 to 2006*. Retrieved from http://escholarship.org/uc/item/7wr0d765.pdf

Horst, A. (2006). Rehabilitation of Urban Forest in Addis Ababa. *Journal of the Dry Land*, *1*(2), 109.

Hoteit, S., Secci, S., Sobolevsky, S., Ratti, C., & Pujolle, G. (2014). Estimating human trajectories and hotspots through mobile phone data. *Computer Networks*, *64*, 296–307. doi:10.1016/j.comnet.2014.02.011

Hou, J. (Ed.). (2010). *Insurgent public space. Guerrilla urbanism and the remaking of contemporary cities*. Abingdon: Routledge.

Huang, Y., & Brodrick, J. (2000). A bottom-up engineering estimate of the aggregate heating and cooling loads of the entire US building stock. In *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings*.

Huawei (n.d.). *Brilliant life powered by smart city.docx*. Retrieved June 16, 2014, from http://www.huawei.com/en/about-huawei/publications/communicate/hw-079367.htm

Hudson-Smith, A. (2014). Tracking, Tagging and Scanning the City. *Architectural Design*, *84*(1), 40–47. doi:10.1002/ad.1700

Hui, J., & Thubert, P. (2011). Compression format for IPv6 datagrams over IEEE 802.15.4-based networks. *RFC 6282*.

Humphries, C. (2013). The too-smart city. Retrieved November, 30, 2014 from http://www.bostonglobe.com/ideas/2013/05/18/the-too-smart-city/q87J17q-CLwrN90amZ5CoLI/story.html

Hunt, P. B., Robertson, D. L., & Bretherton, R. D. (1982). The SCOOT on-line traffic signal optimization technique. *Traffic Engineering & Control*, *23*, 190–192.

Hvelplund, F., Möller, B., & Sperling, K. (2013). Local ownership, smart energy systems and better wind power economy. *Energy Strategy Reviews*, *1*(3), 164–170. doi:10.1016/j.esr.2013.02.001

IBM. (n.d.). *IBM Smarter Planet*. Retrieved June 16, 2014, from http://www.ibm.com/smarterplanet/

Ide, C., Dusza, B., & Wietfeld, C. (2012). Performance Evaluation of V2I-Based Channel Aware Floating Car Data Transmission via LTE. In *Proceedings of IEEE ITSC*. doi:10.1109/ITSC.2012.6338753

IEA. (2011). *Technology Roadmap - Smart Grids*.

IEA. (2014). *The Power of Transformation - Wind, Sun and the Economics of Flexible Power Systems*.

IEEE Computer Society. (2003). *Local and Metropolitan Area Networks - Specific Requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). 802.15.4-2003 - IEEE Standard for Information Technology.*

IEEE Computer Society. (2006). *Local and Metropolitan Area Networks - Specific Requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs). 802.15.4 802.15.4-2006 - IEEE Standard for Information technology*.

IEEE Computer Society. (2012). *802.11-2012 - IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems. Local and Metropolitan Area Networks--Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*.

Institute for Transportation & Development Policy. (2013). *Intelligent transportation systems. ADB knowledge Asia case studies project - Seoul*. New York, NY: Institute for Transportation & Development Policy.

International Association of Traffic and Safety Sciences. (2007). *White paper on traffic safety in Japan*. Japan: International Association of Traffic and Safety Sciences.

International Energy Agency. (2011). *Smart Grids Roadmap*. Retrieved June 09, 2014, from http://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

International Energy Agency. (2012). *Energy Technology Perspectives 2012*. Executive Summary.

International Energy Agency. (2013). *World Energy Outlook: Redrawing the Energy Climate Map*. IEA, Paris Institute for Energy and Transport. (2003). *ESCO Financing Options*. Retrieved from http://iet.jrc.ec.europa.eu/energyefficiency/european-energy-service-companies/financing-options

International Organization for Standardization. (2014). *Sustainable development of communities -- Indicators for city services and quality of life*. International Organization For Standardization.

International Road Traffic and Accident Database. (2006). *BASt site*. Retrieved from http://www.bast.de/EN/Publications/Database/e-itrd/e-itrd-1.html?nn=691198

International Transport Forum. (2014). *IRTAD road safety annual report 2014*. France: International Transport Forum, International Traffic Safety Data and Analysis Group.

Ipeirotis, P. G. (2010). Analyzing the Amazon Mechanical Turk marketplace. *XRDS: Crossroads - The ACM Magazine for Students, 17*(2), 16-21.

Iqbal, M. S., Choudhury, C. F., Wang, P., & González, M. P. (2014). Development of origin-destination matrices using mobile phone call data. *Transportation Research Part C, Emerging Technologies*, *40*, 63–74. doi:10.1016/j.trc.2014.01.002

Irum, S., Alamgir, M., Gul, M., & Osman, A. (2002). Perceptions of Community in Madina Town Towards the Undeveloped Green Spaces in Madina Town. *Pakistan Journal of Applied Sciences*, *2*(12), 1099–1101.

Ishida, T. (2002). Digital City of Kyoto. *Magazine Communications of ACM*, *45*(7), 76–81. doi:10.1145/514236.514238

ISO/IEC/ECMA. (2013). Near Field Communication Interface and Protocol - 2, 3rd Edition.

ISTAT. (2009). *Indicatori ambientali urbani 2009*. Rome, Italy: ISTAT.

ISTAT. (2012). *Dati ambientali nelle città - Mobilità urbana 2012*. Rome, Italy: ISTAT.

ITU. (2012). *Toolkit on environmental sustainability for the ICT sector*. ITU-T.

ITU. (2013). *Focus Group on Smart Sustainable Cities.* Retrieved from http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

ITU. (2014). *ITU-T and Climate Change, Technology Watch Report*.

ITU. (2014). *Smart Sustainable Cities: An Analysis of Definitions*. Retrieved from http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

Izvercianu, M., Şeran, S. A., & Branea, A. M. (2014). Prosumer-oriented Value Co-creation Strategies for Tomorrow's Urban Management. *Procedia: Social and Behavioral Sciences*, *124*, 149–156. doi:10.1016/j.sbspro.2014.02.471

Jaap, S., Bechler, M., & Wolf, L. (2005). Evaluation of routing protocols for vehicular ad hoc networks in typical road traffic scenarios.*Proc of the 11th EUNICE Open European Summer School on Networked Applications*, 584-602.

Jacobs, J. (1961). Gradual money and cataclysmic money. Chapter 16 in J. Jacobs, The Death and Life of Great American Cities. Vintage Books.

Jacobs, J. (1961). *The Death and Life of Great American Cities*. New York: Random House.

Janaka, E., Jenkins, N., Liyanage, K., Wu, J., & Yokoyama, A. (2012). *Smart Grid: Technology and Applications*. New Jersey: Wiley.

Jang, M., & Shu, S. (2010). *U-City: New trends of Urban Planning in Area based on Pervasive and Ubiquitous Geotechnology and Geoinformation*. Berlin: Springer.

Japan Automobile Manufacturers Association. (2012). *Japan's domestic shipments of eco-friendly vehicles in fiscal 2011*. Japan: Japan Automobile Manufacturers Association.

Japan, I. T. S. (2013). *ITS green safety showcase*. Tokyo, Japan: ITS Japan. Retrieved from http://www.its-jp.org/english/its-green-safety-showcase/

Jauhiainen, J., & Suorsa, K. (2008). Triple Helix in the periphery: The case of Multipolis in Northern Finland. *Cambridge Journal of Regions*. *Economy and Society*, *1*(2), 285–301.

Jebaraj, S., & Iniyan, S. (2006). A review of energy models. *Renewable & Sustainable Energy Reviews*, *10*(4), 281–311. doi:10.1016/j.rser.2004.09.004

Jensen, J., & Bjorn, T. (2004). Narrating the Triple Helix concept in "weak" regions: Lessons from Sweden. *International Journal of Technology Management*, *27*(5), 513–530. doi:10.1504/IJTM.2004.004287

Jeon, C. M., & Amekudzi, A. (2005). Addressing sustainability in transportation systems: Definitions, Indicators, and Metrics. *Journal of Infrastructure Systems*, *31*(50).

Jiang, X. (2014). New-energy vehicles 'turning the corner': *ChinaDaily,* 1 July 2014.

Johansson, E., Persson, K., Skold, M., & Sterner, U. (2004, May). An analysis of the fisheye routing technique in highly mobile ad hoc networks. In Vehicular Technology Conference, 2004. VTC 2004-Spring. 2004 IEEE 59th (Vol. 4, pp. 2166-2170). IEEE. doi:10.1109/VETECS.2004.1390657

Joint Programming Initiative. (2010). *URBAN EUROPE: Global Challenges – Local Solutions, presented by Austrian Ministry of Science and Research, Austrian Ministry of Transport, Innovation and Technology, Dutch Ministry of Transport, Public Work and Water Management*. Retrieved March, 16, 2010, from http://www.eurosfaire.prd.fr/7pc/doc/1300116345_jpi_urbaneurope_16_03_2010.pdf

Julian, C., & Olliver, R. (2014). *Community Energy: Unlocking Finance and Investment – The Way Ahead*. Retrieved from http://www.respublica.org.uk/documents/lfv_Community Energy - Unlocking Finance and Investment - The Way Ahead - UPDATED DESIGN.pdf

Juujärvi, S., & Pesso, K. (2013). Actor Roles in an Urban Living Lab: What Can We Learn from Suurpelto, Finland? *Technology Innovation Management Review*. Retrieved from http://timreview.ca/article/742

Kaden, R., & Kolbe, T. H. (2013). City-wide total energy demand estimation of buildings using Semantic 3D city models and statistical data. In Proceedings of Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (vol. II-2/W1).

Kadian, R., Dahiya, R. P., & Garg, H. P. (2007). Energy-related emissions and mitigation opportunities from the household sector in Delhi. *Energy Policy*, *35*(12), 6195–6211. doi:10.1016/j.enpol.2007.07.014

Kajiwara, A. (2012). Overview of FY2020 fuel efficiency standards for passenger vehicles. Environmental Policy Division, Road Transport Bureau, Ministry of Land, Infrastructure, Transport and Tourism.

Kaletka, C., Kopp, R., & Pelka, B. (2011). Social Media Revisited. User Generated Content as a Social Innovation for eInclusion. In *Proceedings of International AAAI Conference on Weblogs and Social Media*. Barcelona, Spain.

Kamal, N., Fels, S., & Fergusson, M. (2014). Online social networks for health behaviour change: Designing to increase socialization. *Computers in Human Behavior*, *41*, 444–453. doi:10.1016/j.chb.2014.03.068

Kaminska, I. (2014). A game of mega-city states. Retrieved from Financial Times Alphaville: http://ftalphaville.ft.com/2014/06/18/1879892/a-game-of-mega-city-states/

Kammeier, H. (1999). New tools for spatial analysis and planning as components of an incremental planning-support system. *Environment and Planning. B, Planning & Design*, *26*(3), 365–380. doi:10.1068/b260365

Kanchev, H., Di, L., Colas, F., Lazarov, V., & Francois, B. (2011). Energy Management and Operational Planning of a Microgrid with a PV-Based Active Generator for Smart Grid Applications. *IEEE Transactions on Industrial Electronics*, *58*(10), 4583–4592. doi:10.1109/TIE.2011.2119451

Kang, K., & Kim, I. (2001). Effective policy of ITS for Seoul Korea. In *Proceedings of the Eastern Asia Society for Transportation Studies*.

Kanter, R. M., & Litow, S. S. (2009). *Informed and Interconnected: A Manifesto for Smarter Cities*. Retrieved November 30, 2014 from http://www.hbs.edu/faculty/Publication%20Files/09-141.pdf

Karalis, A., Joannopoulos, J. D., & Soljačić, M. (2008). Efficient wireless non-radiative mid-range energy transfer. *Annals of Physics*, *323*(1), 34–48. doi:10.1016/j.aop.2007.04.017

Kato, K. (2002). *Development of ITS in Japan - Focusing on DSRC*. In *Proceedings of 10th World Congress on ITS*. Madrid, Spain.

Kearney, A. T. (2013). The Mobile Economy 2013. Retrieved from http://www.gsmamobileeconomy.com/GSMA%20Mobile%20Economy%202013.pdf

Keirstead, J. (2011). *Types of urban energy system models*. Retrieved June 05, 2014, from http://www.jameskeirstead.ca/blog/types-of-urban-energy-system-models/

Keirstead, J., Jennings, M., & Sivakumar, A. (2012). A review of urban energy system models: Approaches, challenges and opportunities. *Renewable & Sustainable Energy Reviews*, *16*(6), 3847–3866. doi:10.1016/j.rser.2012.02.047

Keirstead, J., Samsatli, N., & Shah, N. (2009). SynCity: an integrated tool kit for urban energy systems modelling. In *Proceedings of Urban Research Symposium*.

Kelly-Detwiler, P. (2014, March 18). The Afterlife For Electric Vehicle Batteries: A Future Source Of Energy Storage? Forbes. Retrieved June 15, 2014, from http://www.forbes.com/sites/peterdetwiler/2014/03/18/the-afterlife-for-electric-vehicle-batteries-a-future-source-of-energy-storage/

Kenen, P. (1969). The Theory of Optimum Currency Areas: An Eclectic View. In R. A. Mundell & A. K. Swoboda (Eds.), *Monetary problems of the international economy*. Chicago: University of Chicago Press.

Kennedy, S. J. (2012). *Transforming Big Data Into Knowledge: Experimental Techniques in Dynamic Visualization.* (Doctoral dissertation). Massachusetts Institute of Technology.

KfW. (2011). *Annual Report*. KfW Bankengruppe. Retrieved from https://www.kfw.de/Download-Center/Finanzpublikationen/Financial-publications-PDFs/1_Geschäftsberichte-E/Geschäftsbericht_2011_E.pdf

Khamid, H. M. A. (2013). Singaporeans' satisfaction with public transport drops. Singapore: Channel News Asia, 12 March 2013.

King, C., Griggs, W., Wirth, F., & Shorten, R. (2013, June). Using A Car Sharing Model To Alleviate Electric Vehicle Range Anxiety. In he 16th Yale Workshop on Adaptive and Learning Systems.

King, C., Griggs, W., Wirth, F., Quinn, K., & Shorten, R. (2013). Alleviating a form of electric vehicle range anxiety through On-Demand vehicle access. arXiv preprint arXiv:1312.5939.

King, R. (2011). *Building a Subversive Grassroots Network. Spectrum*. IEEE.

Kioutsioukis, I., Kouridis, C., Gkatzoflias, D., Dilara, P., & Ntziachristos, L. (2010). Uncertainty and Sensitivity Analysis of National Road Transport Inventories Compiled with COPERT 4. *Procedia: Social and Behavioral Sciences*, *2*(6), 7690–7691. doi:10.1016/j.sbspro.2010.05.181

Kitchin, R. (2014b). *Knowing and Governing Cities Through Urban Indicators, City Benchmarking and Real-Time Dashboards*. Retrieved from https://www.maynoothuniversity.ie/progcity/

Kitchin, R. (2014a). *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences*. London: Sage. doi:10.4135/9781473909472

Kittur, A., Chi, E., Pendleton, B. A., Suh, B., & Mytkowicz, T. (2007). Power of the few vs. wisdom of the crowd: Wikipedia and the rise of the bourgeoisie. *World Wide Web (Bussum)*, *1*(2), 19.

Kjems, E., & Wen, W. (2011). A 3D city model used as user-interface for an energy-system. In *Proceedings of International Conference on Computers in Urban Planning and Urban Management* (pp. 37-46).

Kloppmann, M., Koenig, D., Leymann, F., Pfau, G., Rickayzen, A., von Riegen, C., . . . Trickovic, I. (2005). Ws-bpel extension for people–bpel4people. *Joint white paper, IBM and SAP*.

Klosterman, R. (1999). The What if? collaborative planning support system. *Environment and Planning. B, Planning & Design*, *26*(3), 393–408. doi:10.1068/b260393

Klosterman, R. E. (1994). Large-Scale urban models - Retrospect and prospect. *Journal of the American Planning Association*, *60*(1), 3–6. doi:10.1080/01944369408975545

Knetsch, T. A. (2009). *Trend and cycle features in German residential investment before and after unification*. Frankfurt am Main: Deutsche Bundesbank, Economics Department.

Ko, Y. D., Jang, Y. J., & Jeong, S. (2012, August). Mathematical modeling and optimization of the automated wireless charging electric transportation system. In Automation Science and Engineering (CASE), 2012 IEEE International Conference on (pp. 250-255). IEEE. doi:10.1109/CoASE.2012.6386482

Koch, M., Harnisch, J., Blok, K. (2003). *Systematische Analyse der Eigenschaft von Energiemodellen im Hinblick auf ihre Eignung für möglichst praktische Politik-Beratung zur Fortentwicklung der Klimaschutzstrategie*.

Koch, A., Girard, S., & McKoen, K. (2012). Towards a neighbourhood scale for low-or zero-carbon building projects. *Building Research and Information*, *40*(4), 527–537. doi:10.1080/09613218.2012.683241

Kolbe, T. H. (2009). *Representing and exchanging 3D city models with CityGML. 3D geo-information sciences* (pp. 15–31). Berlin: Springer. doi:10.1007/978-3-540-87395-2_2

Komninos, N. (2008). *Intelligent Cities and Globalisation of Innovation Networks*. London: Taylor & Francis.

Komninos, N., Pallot, M., & Schaffers, H. (2012). Special Issue on Smart Cities and the Future Internet in Europe. *Journal of Knowledge Economy*, *4*(2), 119–134. doi:10.1007/s13132-012-0083-x

Komninos, N., & Tsarchopoulos, P. (2012). Intelligent Thessaloniki: From agglomeration of apps to smart districts. *Journal of Knowledge Economy*, *4*(2), 149–168. doi:10.1007/s13132-012-0085-8

Koo, R. C. (2013). *Central Banks in Balance Sheet Recessions: A Search for Correct Response*. Nomura Research Institute.

Korea Advanced Institute of Science & Technology. (2013). *Concept of online electric vehicle project*. Korea: KAIST. Retrieved from http://olev.kaist.ac.kr/en/olevco/1.php

Korea Expressway Corporation. (2009). *ETMS (Expressway Traffic Management System)*. Retrieved from http://www.ex.co.kr/english/business/EX_opp/its/its.jsp

Kremers, E. (2013). *Modelling and simulation of electrical energy systems through a complex systems approach using agent-based models*. Karlsruhe: KIT Scientific Publishing.

Kremers, E., Durana, J., Barambones, O., & Koch, A. (2012). Towards complex system design and management in the engineering domain – the smart grid challenge. In *Proceedings of European Conference on Complex Systems*.

Krüger, A., & Kolbe, T. H. (2012). Building analysis for urban energy planning using key indicators on virtual 3D city models - the Energy Atlas of Berlin. In *Proceedings of Archives of the Photogrammetry* (Vol. 39, pp. 1–25). Remote Sensing and Spatial Information Sciences.

Krugman, P. (2013). Revenge of the Optimum Currency Area. In D. Acemoglu, J. Parker, & M. Woodford, NBER Macroeconomics Annual 2012, Volume 27 (pp. 439-448). University of Chicago Press. doi:10.1086/669188

Krugman, P. (2013). Currency Regimes, Capital Flows, and Crises.*14th Jaques Polak Annual Research Conference*. Washington D.C.: International Monetary Fund.

Kuester, K., Müller, G. J., & Stölting, S. (2007). Is the Keynesian Phillips Curve Flat? Working Paper Series 809, pp. 3-33.

Kung, K. S., Greco, K., Sobolevsky, S., & Ratti, C. (2014). Exploring universal patterns in human home-work commuting from mobile phone data. *PLoS ONE*, *9*(6), 16. doi:10.1371/journal.pone.0096180 PMID:24933264

Kurs, A. (2007). Power transfer through strongly coupled resonances (Doctoral dissertation, Massachusetts Institute of Technology).

Kurucz, C. N., Brandt, D., & Sim, S. (1996). A linear programming model for reducing system peak through customer load control programs. *IEEE Transactions on Power Systems*, *11*(4), 1817–1824. doi:10.1109/59.544648

Kushalnagar, N., Montenegro, G., & Schumacher, C. (2007). IPv6 over low-power wireless personal area networks (6LowPan): Overview, assumptions, problem statement, and goals. *RFC 4919*.

Kwai Fun, R., & Wagner, C. (2008). Weblogging: A study of social computing and its impact on organizations. *Decision Support Systems*, *45*(2), 242–250. doi:10.1016/j.dss.2007.02.004

Kwok, J. (2014, June). Car, taxi and bus - how the costs stack up. Singapore. *Sunday Times*, 29.

Land Transport Authority. (2006). *Project safety review (safe-to-build) process*. Singapore: Land Transport Authority.

Landis, J. D., Monzon, J. P., Reilly, M., & Cogan, C. (1998). *The California Urban and Biodiversity Analysis Model: Theory and Pilot Implementation*. Berkeley: UC Berkeley, Institute of Urban and Regional Development.

Landry, C. (2008). *The Creative City*. London: Earthscan.

Lane, N. D., Miluzzo, E., Lu, H., Peebles, D., Choudhury, T., & Campbell, A. T. (2010). A survey of mobile phone sensing. *IEEE Communications Magazine*, *48*(9), 140–150. doi:10.1109/MCOM.2010.5560598

Larsen, P. H., Goldman, C. A., & Satchwell, A. (2012). Evolution of the U.S. energy service company industry: Market size and project performance from 1990–2008. *Energy Policy*, *50*, 802–820. doi:10.1016/j.enpol.2012.08.035

Larson, R. G., & Odoni, A. R. (1981). *Urban Operations Research*. NJ: Prentice-Hall.

Lashkari, K., Shladover, S. E., & Lechner, E. H. (1986). Inductive power transfer to an electric vehicle. In International Electric Vehicle Symposium (8th: 1986: Washington DC).

Laudon, K. C., & Laudon, J. P. (2000). *Les systèmes d'information de gestion*. Canada: Pearson Education.

Laurini, R. (1998). Groupware for urban planning: An introduction. *Computers, Environment and Urban Systems*, *22*(4), 317–333. doi:10.1016/S0198-9715(98)00029-5

Leanza, E., & Carbonaro, G. (2013). Making European Cities more Affordable. *Productive and Sustainable. L'industria*, *2*, 275–294.

Lee, K., Lee, J., Yi, Y., Rhee, I., & Chong, S. (2010). Mobile Data Offloading: How Much Can Wi-Fi Deliver? In *Proceedings of IEEE/ACM CoNEXT*.

Lee, S., & Ng, W.-S. (2004). Rapid motorization in China: Environmental and social challenges. *ADB-JBIC-World Bank East Asia and Pacific Infrastructure Flagship Study*.

Lee, S., Huh, J., Park, C., Choi, N. S., Cho, G. H., & Rim, C. T. (2010, September). On-Line Electric Vehicle using inductive power transfer system. In Energy Conversion Congress and Exposition (ECCE), 2010 IEEE (pp. 1598-1601). IEEE. doi:10.1109/ECCE.2010.5618092

Lee, D. B. (1994). Retrospective on large-scale urban models. *Journal of the American Planning Association*, *60*(1), 35–40. doi:10.1080/01944369408975549

Lee, D. B. Jr. (1973). Requiem for Large-Scale Models. *Journal of the American Institute of Planners*, *39*(3), 163–177. doi:10.1080/01944367308977851

Lee, D., Offenhuber, D., Biderman, A., & Ratti, C. (2014). Learning from tracking waste: How transparent trash networks affect sustainable attitudes and behavior. In *Proceedings of IEEE World Forum on Internet of Things* (pp. 130-134). doi:10.1109/WF-IoT.2014.6803134

Lee, J. (2012). *Economic growth and transport models in Korea* (pp. 260–285). Korea: Korea Transport Institute.

Lee, J., Kim, D., Kwon, Y., & Ha, S. (2012). *A comparison study on two bike sharing programs in Korea*. In *Proceedings of Annual Meeting Transportation Research Board*.

Lefebvre, H. (1991). *The production of space*. Blackwell.

Leong, J. (2014). Singapore-Taiwan cross-border contactless card in the works. Retrieved from http://www.channelnewsasia.com/news/singapore/singapore-taiwan-cross/1132598.html

Leon-Garcia, A., & Mohsenian-Rad, A.-H. (2010). Optimal residential load control with price prediction in real-time electricity pricing environments. *IEEE Transactions on Smart Grid*, *1*(2), 120–133. doi:10.1109/TSG.2010.2055903

Lessig, L. (2004). *Free culture: How big media uses technology and the law to lock down culture and control creativity*. New York, NY: The Penguin Press.

Levinson, H., Zimmerman, S., Clinger, J., Gast, J., Rutherford, S., & Bruhn, E. (2003). Bus Rapid Transit: Vol. 2. *Implementation Guidelines*. Washington, DC: Transportation Research Board, National Academies.

Lew, Y.D., & Ang, C.I. (2010). The LTA Journey: 15 Years. *JOURNEYS.*

Leydesdorff, L., & Deakin, M. (2011). The triple helix of smart cities: A neo-evolutionary perspective. *Journal of Urban Technology*, *18*(2), 53–63. doi:10.1080/10630732.2011.601111

Leydesdorff, L., & Fritsch, M. (2006). Measuring the knowledge base of regional innovation systems in Germany in terms of a triple helix dynamics. *Research Policy*, *35*(10), 1538–1553. doi:10.1016/j.respol.2006.09.027

Leydesdorff, L., & Sun, Y. (2009). National and international dimensions of the triple helix in Japan: University-industry-government versus international co-authorship relations. *Journal of the American Society for Information Science and Technology*, *60*(4), 778–788. doi:10.1002/asi.20997

Lima, M. (2011). *Visual Complexity: Mapping Patterns of Information*. New York: Princeton Architectural Press.

Lin, X., Andrews, J., Ghosh, A., & Ratasuk, R. (2014). An Overview of 3GPP Device-to-Device Proximity Services. *IEEE Communications Magazine*, *52*(4), 40–48. doi:10.1109/MCOM.2014.6807945

Little, J., Kelson, M. D., & Gartner, N. H. (1981). Maxband: A program for setting signals on arteries and triangular networks. *Transportation Research Record*, *795*, 40–46.

Liu, C., Chau, K. T., Wu, D. I. Y. U. N., & Gao, S. H. U. A. N. G. (2013). *Opportunities and Challenges of Vehicle-to-Home*. Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies.

Liu, Z. (2007). A survey of intelligent methods in urban traffic signal control. *International Journal of Computer Science and Network Security*, *7*(7), 105–112.

Local Governments for Sustainability. (2011). *Hangzhou, China, the world's largest bike sharing program*. Retrieved from http://www.ecomobility.org/fileadmin/template/project_templates/ecomobility/files/Publications/Case_stories_EcoMobility_Hangzhau_PDF_print.pdf

Loibl, W., Vielguth, S., Peters-Anders, J., Möller, S., Jakutyte-Walangitang, D., Brinkman, J., . . . Fumarola, M. (2014). The TRANSFORM DSE - an interactive decision support environment for serving smart city strategy-development and local measure implementation. In Proceedings of Real Corp (pp. 711-720).

Lombardi, P., Cooper, I., Paskaleva, K., & Deakin, M. (2009). The challenge of designing user-centric e-services: European dimensions. In C. Reddick (Ed.), *Strategies for local e-government adoption and implementation: comparative studies*. Hershey, PA: Idea Group Publishing. doi:10.4018/978-1-60566-282-4.ch024

Lombardi, P., Giordano, S., Caragliu, A., Del Bo, C., Deakin, D., Nijkamp, P., & Farouh, H. et al. (2012). An Advanced Triple-Helix Network Model for Smart Cities Performance. In O. Y. Ercoskun (Ed.), *Green and Ecological Technologies for Urban Planning: Creating Smart Cities*. Hershey, PA: Information Science Publishing. doi:10.4018/978-1-61350-453-6.ch004

Lombardi, P., Huovila, P., & Niitamo, V.-P. (2010). Metrics for Value Creation in a Sustainable Knowledge Society. In *Proceeding of World Building Congress* (pp. 28-38).

Lowrie, P. (1982). The Sydney co-ordinated adaptive traffic system - principles, methodology, algorithms. In *Proceedings of the IEE Conference on Road Traffic Signaling* (pp. 67-70).

Loy, D., Dietrich, D., & Schweinzer, H.-J. (2001). *Open control networks: LonWorks/EIA 709 technology*. New York: Springer. doi:10.1007/978-1-4615-1475-6

Luederitz, C., Lang, D. J., & Von Wehrden, H. (2013). A systematic review of guiding principles for sustainable urban neighborhood development. *Landscape and Urban Planning*, *118*, 40–52. doi:10.1016/j.landurbplan.2013.06.002

Lundvall, B. (1992). *National Systems of Innovation*. London: Pinter.

Luoma, J., & Sivak, M. (2006). *Characteristics and availability of fatal road-crash databases worldwide*. Transportation Research Institute, University of Michigan.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press.

MacKerron, G., & Mourato, S. (2013). Happiness is Greater in Natural Environments. *Journal of Global Environmental Change*, *23*(5), 992–1000. doi:10.1016/j.gloenvcha.2013.03.010

Madden, M. (2007). *Digital Footprints: Online identity management and search in the age of transparency*. Washington, DC: Pew Internet & American Life Project.

Malina, A., & Ball, I. (2005). ICTs and community: Some suggestions for further research in Scotland. *Journal of Community Informatics*, *1*(3), 66–83.

Malina, A., & McIntosh, A. (2004). Bridging the digital divide: The development in Scotland. In A. V. Anttiroiko et al. (Eds.), *eTransformation in Governance*. London: Idea Group Publishing. doi:10.4018/978-1-59140-130-8.ch013

Mangel, T., Kosch, T., & Hartenstein, H. (2010). A Comparison of UMTS and LTE for Vehicular Safety Communication at Intersections. In *Proceedings of IEEE VNC*.

Mangiatordi, F., Pallotti, E., Del Vecchio, P. & Leccese, F. (2012). Power consumption scheduling for residential buildings. *Environment and Electrical Engineering*, 926-930.

Mankiw, N. G., & Weil, D. N. (1989). The Baby Boom, the Baby Burst, and the Housing Market. *Regional Science and Urban Economics*, *19*(2), 235–258. doi:10.1016/0166-0462(89)90005-7 PMID:12283640

Manville, C., ... (2014). *Mapping Smart Cities in the EU*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

Manzoni, V., Manilo, D., Kloeckl, K., & Ratti, C. (2010). Transportation mode identification and real-time CO2 emission estimation using smartphones. Retrieved November 30, 2014, from http://senseable.mit.edu/co2go/images/co2go-technical-report.pdf

Marino, A., Bertoldi, P., Rezessy, S., & Boza-Kiss, B. (2011). A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. *Energy Policy*, *39*(10), 6190–6198. doi:10.1016/j.enpol.2011.07.019

Marsan, M., Chiaraviglio, L., Ciullo, D., & Meo, M. (2009). Optimal energy savings in cellular access networks. In *Proceedings of IEEE ICC Workshops*.

Martelli, F., Renda, M. E., Resta, G., & Santi, P. (2012). A measurement-based study of beaconing performance in IEEE 802.11p vehicular networks. In Proceedings of IEEE INFOCOM.

Martinez-Balleste, A., Perez-Martinez, P. A., & Solanas, A. (2013). The Pursuit of Citizens' Privacy: A Privacy-Aware Smart City is Possible. *IEEE Communications Magazine*, *51*(6), 136–141. doi:10.1109/MCOM.2013.6525606

Martins, J. (1978). *The Wired Society*. New Jersey: Prentice-Hall.

Masala, E., & Melis, G. (Eds.). (2014). *Interactive Visualisation tool for brownfield redevelopment - A European experience*. Torino, Italia: Celid.

Mashable. (2012). *How Much Data is Created Every Minute?* Retrieved from http://mashable.com/2012/06/22/data-created-every-minute/

Masud, L., Valsecchi, F., Ciuccarelli, P., Ricci, D., & Caviglia, G. (2010). From Data to Knowledge - Visualizations as Transformation Processes within the Data-Information-Knowledge Continuum. In *Proceedings of International Conference Information Visualisation*. doi:10.1109/IV.2010.68

Mc Dermott, R. (1999). Why information technology inspired but cannot deliver knowledge management. *California Management Review*, *41*(3), 103–117. doi:10.2307/41166012

McCarthy, J., & Peach, R. W. (2002). *Monetary Policy Transmission to Residential Investment*. FRBNY Economic Policy Review.

McLuhan, M., & Gordon, W. T. (2011). *Counterblast 1954*. Hamburg, Germany: Gingko Press Inc.

Mercer. (2012). *2012 Quality of Living Survey*. Mercer. Retrieved June 16, 2014, from http://www.mercer.com/newsroom/2014-quality-of-living-survey.html

Merz, H., Backer, J., Moser, V., Hansemann, T., Greefe, L., & Hübner, C. (2009). *Building Automation: Communication Systems with EIB/KNX, LON and BACnet*. New York: Springer. doi:10.1007/978-3-540-88829-1

Metrex. (2014). *ReMAC Planung für Energie*. Retrieved June 05, 2014, from http://www.regenerative-energy.org/DE/metrex.php

Milcheva, S., & Sebastian, S. (2010). *Housing Channels of Monetary Policy Transmission in European Industrial and Transition Countries*. European Real Estate Society.

Mimbela, L., & Klein, L. (2000). *A summary of vehicle detection and surveillance technologies used in intelligent transportation systems*. Retrieved September 2014 from http://ntl.bts.gov/lib/10000/10000/10041/029prs.pdf

Ministry of Environment. (2008). *A protocol target achievement plan (revision)*. Japan: Ministry of Environment.

Ministry of Federal Affairs. (2006). *Urban Development Policy*. Addis Ababa, Ethiopia.

Ministry of Finance. (2013). *Factsheet on Singapore air quality. Budget Singapore 2013*. Singapore: Ministry of Finance.

Ministry of Land. Infrastructure, Transport and Tourism. (2001). *White paper on land, infrastructure and transport in Japan*. Japan: Ministry of Land, Infrastructure and Transport.

Ministry of Land. Infrastructure, Transport and Tourism. (2009). Efforts for environmentally sustainable transport in Japan. Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Ministry of Land. Infrastructure, Transport and Tourism. (2012). ITS initiatives in Japan. Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Ministry of Land. Infrastructure, Transport and Tourism. (2013a). The micro mobility and future development. Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Ministry of Land. Infrastructure, Transport and Tourism. (2013b). Partial amendments of the "Safety Regulations for Road Transport Vehicle", and the "Public Notice that prescribes Details of Safety Regulations for Road Transport Vehicle". Japan: Ministry of Land, Infrastructure, Transport and Tourism.

Minsky, H. P. (1992). The Financial Instability Hypothesis. Working Paper (74). The Jerome Levy Economics Institute of Bard College.

Mishkin, F. (2001). *The Transmission Mechanism and the Role of Asset Prices in Monetary Policy*. The National Bureau of Economic Research. doi:10.3386/w8617

Mishkin, F. (2007). *Housing and the Monetary Transmission Mechanism*. The National Bureau of Economic Research. doi:10.3386/w13518

Mishkin, F. S. (2000). *Lessons from the Asian Crisis*. The National Bureau of Economic Research. doi:10.3386/w7102

Mishkin, F. S. (2011). *Monetary Policy Strategy: Lessons from the Crisis*. The National Bureau of Economic Research. doi:10.3386/w16755

Mitchell, W. (2007). *Intelligent cities*. Retrieved from http://www.uoc.edu/uocpapers/5/dt/eng/mitchell.pdf

Mitchell, W. J. (1999). *E-topia: « Urban life, Jim (but not as we know it)*. Cambridge, MA: MIT Press.

Mlot, S. (2013). *Microsoft City Next Aims to Build 'Smart Cities'*. Retrieved June 16, 2014, from http://www.pcmag.com/article2/0,2817,2421635,00.asp

Modigliani, F. (1986). Life Cycle, Individual Thrift, and the Wealth of Nations. *The American Economic Review*, *73*(3), 297–313. PMID:17744469

Modigliani, F., & Miller, M. H. (1958). The Cost of Capital, Corporation Finance and the Theory of Investment. *The American Economic Review*, *48*(3), 261–298.

Mohan, R., & Kapur, M. (2014). *Monetary Policy Coordination and the Role of Central Banks*. International Monetary Fund.

Mohrehkesh, S., & Nadeem, T. (2011, October). Toward a wireless charging for battery electric vehicles at traffic intersections. In Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on (pp. 113-118). IEEE. doi:10.1109/ITSC.2011.6083137

Mohsenian-Rad, A. H., Wong, V. W. S., Jatskevich, J. & Schober, R. (2010). Optimal and autonomous incentive-based energy consumption scheduling algorithm for smart grid. *Innovative Smart Grid Technologies*, 1-6.

Molderink, A., Bakker, V., Bosman, M. G. C., Hurink, J. L., & Smit, G. J. M. (2009). *Domestic energy management methodology for optimizing efficiency in Smart Grids. In proceedings of* (pp. 1–7). IEEE Bucharest PowerTech. doi:10.1109/PTC.2009.5281849

Molinari, F. (2011). Living Labs as Multi-Stakeholder Platforms for the eGovernance of Innovation. In *Proceedings of the ICEGOV11 Conference*. Tallin, Estonia. doi:10.1145/2072069.2072092

Momoh, J. (2012). *Smart Grid: Fundamentals of Design Analysis*. New Jersey: Wiley-IEEE Press. doi:10.1002/9781118156117

Montenegro, G., Kushalnagar, N., Hui, J., & Culler, D. (2007). Transmission of IPv6 packets over IEEE 802.15.4 networks. *RFC 4944*.

Moon, J. W., & Hoon, H. S. (2011). Thermostat strategies impact on energy consumption in residential buildings. *Energy and Building*, *43*(2-3), 338–346. doi:10.1016/j.enbuild.2010.09.024

Moore, S. (2011). Understanding and managing anti-social behaviour on public transport through value change: The considerate travel campaign. *Transport Policy*, *18*(1), 53–59. doi:10.1016/j.tranpol.2010.05.008

Moretti, E. (2012). *The New Geography of Jobs*. Houghton Mifflin Harcourt.

Mosaic. (2014). Retrieved May 15, 2014, from https://joinmosaic.com/

Motavalli, J. (2010). China to subsidize electric cars and hybrids, *The New York Times*.

Motavalli, J. (2013, June 1). Fallout From Failure of Battery Swap Plan. The New York Times. Retrieved June 14, 2014, from http://www.nytimes.com/2013/06/02/automobiles/fallout-from-failure-of-battery-swap-plan.html?_r=0

Moulaert, F. (2010). Social Innovation And Community Development: Concepts, Theories And Challenges. In F. Moulaert, E. Swyngedouw, F. Martinelli, & S. Gonzalez (Eds.), *Can Neighbourhood save the city? Community development and social innovation*. Abingdon: Routledge.

Moulgan, G. (2007). *Social innovation. What it is, why it matters and how it can be accelerated*. Oxford SAID Business School. Retrieved from http://eureka.bodleian.ox.ac.uk/761/1/Social_Innovation.pdf

Mouradian, A., Augé-Blum, I., & Valois, F. (2014). RTXP: A Localized Real-Time MAC-Routing Protocol for Wireless Sensor Networks. *Computer Networks*, *67*, 43–59. doi:10.1016/j.comnet.2014.03.020

Moustafa, H., & Zhang, Y. (2009). *Vehicular Networks - Techniques, Standards, and Applications*. Auerbach Publications. doi:10.1201/9781420085723

Mulgan, G., & Albury, D. (2003). *Innovations in the Public Sector*. London: Cabinet Office.

Mulligan, G. (2007). *The 6lowpan architecture*. EmNets. doi:10.1145/1278972.1278992

Münchau, W. (2014). Europe faces the horrors of its own house of debt. Financial Times. Retrieved from http://www.ft.com/intl/cms/s/0/beef494e-f255-11e3-9e59-00144feabdc0.html#axzz3BVLfYQ00

Mundell, R. (1961). A Theory of Optimum Currency Areas. *The American Economic Review*, 657–665.

Mun, M., Reddy, S., Shilton, K., Yau, N., Burke, J., Estrin, D., & Boda, P. et al. (2009). PEIR, the personal environmental impact report, as a platform for participatory sensing systems research. In *Proceedings of 7th International Conference on Mobile Systems, Applications, and Services* (pp. 55-68). doi:10.1145/1555816.1555823

Murakami, S., Asamai, Y., Ikaga, T., Yamaguchi, N., & Kaburagi, S. (2011). Development of comprehensive city assessment tool: CASBEE-City. *Building Research and Information*, *39*(3), 195–210. doi:10.1080/09613218.2011.563920

Næss, P. (2013). Residential location, transport rationales and daily-life travel behaviour: The case of Hangzhou Metropolitan Area, China. *Progress in Planning*, *79*, 1–50. doi:10.1016/j.progress.2012.05.001

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. Retrieved November, 30, 2014 from https://bitcoin.org/bitcoin.pdf

Nam, D., & Pardo, T. A. (2011). Smart City as Urban Innovation: Focusing on Management, Policy, and Context. In *Proceedings of ICEGOV2011 Conference*. Tallinn, Estonia. doi:10.1145/2072069.2072100

Nam, T., & Pardo, T. A. (2009). Conceptualizing Smart City with Dimensions of Technology, People, and Institutions. In *Proceedings of Annual International Conference on Digital Government Research*.

Nam, T., & Pardo, T. A. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In *Proceedings of International Digital Government Research Conference: Digital Government Innovation in Challenging Times* (pp. 282-291). doi:10.1145/2037556.2037602

Nasrudin, N., & Nor, A. R. M. (2013). Travelling to School: Transportation Selection by Parents and Awareness towards Sustainable Transportation. *Procedia -. Environmental Sciences*, *17*, 392–400.

National Transport Commision. (2011). *National In-vehicle telematics strategy*. Australia: The Road Freight Sector, National Transport Commission.

National Transport Information Center. (2014). *Introduction to intelligent transport systems. Republic of South Korea*. National Transport Information Center.

Nazareth, N. J. (1987). *Computer solutions of linear program*. New York, NY: Oxford University Press.

Negre, E., & Rosenthal-Sabroux, C. (2014). Recommendations to improve the smartness of a city. In R. P. Dameri & C. Rosenthal-Sabroux (Eds.), *Smart city - How to create public and economic value with high technology in urban space*. Berlin, Germany: Springer. doi:10.1007/978-3-319-06160-3_5

Negroponte, N. (1995). *Being Digital. New York, NY*. Alfred: Knopf.

Nelson, R. (1993). *National Innovation Systems: A comparative analysis*. New York: Oxford University Press.

Nelson, R., & Winter, S. (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap Press of Harvard University.

Neumark, D., & Simpson, H. (2014, April). Place-Based Policies. Working Paper No. 20049. The National Bureau of Economic Research.

Newell, S., Scarbrough, H., Swan, J., & Hislop, D. (2000). Intranets and Knowledge Management: De-centred Technologies and the Limits of Technological Discourse. In C. Prichard, R. Hull, M. Chumer, & H. Willmostt (Eds.), *Managing Knowledge: Critical Investigations of Work and Learning*. UK: Macmillan Business.

Nghiem, T. X., Behl, M., Mangharam, R., & Pappas, G. J. (2011). Green scheduling of control systems for peak demand reduction. In *Proceedings of Decision and Control and European Control Conference* (pp. 5131-5136). doi:10.1109/CDC.2011.6161164

Nitsch, J., Pregger, T., Scholz, Y., Sterner, M., Gerhardt, N., von Oehsen, A., Wenzel, B. (2010) *Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global.*

Nokia Solutions and Networks. (n.d.). *The ICT behind cities of the future*. Retrieved June 16, 2014, from http://nsn.com/news-events/publications/unite-magazine-february-2010/the-ict-behind-cities-of-the-future

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-Creating Company*. Oxford, UK: Oxford University Press.

Nooteboom, B. (2008). Cognitive distance between communities of practice and in firms. In A. Amin & J. Roberts (Eds.), *Community, Economic Creativity and Organisation*. Oxon: Oxford University Press. doi:10.1093/acprof:oso/9780199545490.003.0006

Norair, J. P. (2009). Introduction to DASH7 technologies. Retrieved November 30, 2014, from https://dash7.memberclicks.net/assets/PDF/dash7%20wp%20ed1.pdf

NSLSC. (2011). *BPCDM Office Annual Report.*

NSLSC. (2011). *BPCDM Office Street Trees Inventory Report.*

NTT. (2013). *Vision of a Smart Sustainable City*. Retrieved June 15, 2014 from http://ifa.itu.int/t/fg/ssc/docs/1309-Madrid/in/fg-ssc-0035-japan_NTT_fujitsu.doc

Nurcam, S., & Rolland, C. (2006). *50 ans de Système d'Information: de l'automatisation des activités individuelles à l'amélioration des processus et la creation de valeur ajoutée*. Retrieved from http://www.univ-paris1.fr/fileadmin/diplome_mastersic/chapitreSI_anniversaire.pdf

Nyerges, T., & Jankowski, P. (1997). Adaptive structuration theory: A theory of GIS-supported collaborative decision making. *Geographical Systems*, *4*(3), 225–259.

O'Brien, O., Batty, M., Gray, S., Cheshire, J., & Hudson-Smith, A. (2014). On City Dashboards and Data Stores. In *Proceedings of Workshop on Big Data and Urban Informatics*. University of Illinois at Chicago, Chicago, IL.

O'Mahony, S., & Ferraro, F. (2007). The emergence of governance in an open source community. *Academy of Management Journal*, *50*(5), 1079–1106. doi:10.5465/AMJ.2007.27169153

OECD. (2009). *How Regions Grow: Trends and Analysis*. OECD.

OECD. (2011). *Green Energy Studies: Energy*. Paris, France: OECD Publishing.

OECD. (2011). *Urban Environmental Indicators for Green Cities: A tentative indicator set, Working Party on Environmental Indicators*. Paris, France: OECD.

OECD. (2012). *ICT Applications for the Smart Grid: Opportunities and Policy Implications*. Retrieved May 31, 2014, from10.1787/5k9h2q8v9bln-en

OECD. (2012). *Redefining "Urban": a new way to measure metropolitan areas*. Paris, France: OECD.

OECD. (2013). *Definition of Functional Urban Areas (FUA) for the OECD Metropolitan Database*. OECD.

Oguz, D. (2000). User Survey of Ankara's Parks. *Elsevier Science: Landscape and Urban Planning*, *52*(2), 165–171.

Okay, N., & Akman, U. (2010). Analysis of ESCO activities using country indicators. *Renewable & Sustainable Energy Reviews*, *14*(9), 2760–2771. doi:10.1016/j.rser.2010.07.013

Olariu, S., & Weigle, M. (2009). *Vehicular Networks from Theory to Practice*. Chapman Hall/CRC. doi:10.1201/9781420085891

Ōmae, K. (1995). *The End of the Nation State: The Rise of Regional Economies*. Simon and Schuster.

Ono, Y., Silcock, D., & Gloria, G.-T. (2013). International lessons for road safety in the People's Republic of China. *ADB East Asia Working Paper Series.*

ORAAMP. (1996). Addis Ababa in Action: City Development Plan 2001-2010. Addis Ababa, Ethiopia.

Oracle. (2011). *Oracle's Solutions for Smart Cities: Delivering 21st Century Services*. Oracle. Retrieved June 16, 2014 from http://www.oracle.com/us/industries/public-sector/032422.pdf

Organisation for Economic Co-operation and Development. (2013). *Funding urban public transport, case study compendium*. Paris, France: Organisation for Economic Co-operation and Development.

Osimo, D., Zinnbauer, D., & Bianchi, A. (Eds.). (2007). *The future of eGovernment. An exploration of ICT-driven models of eGovernment for the EU in 2020*. European Commission, Joint Research Centre, Institute for Prospective Technological Studies. Retrieved from http://ftp.jrc.es/eur22897en.pdf

Ou, H. (2013). Beijing ETC system to be linked to Shangdong, Shanxi, *China Daily*.

Palensky, P., & Kupzog, F. (2013). Smart Grids. *Annual Review of Environment and Resources*, *38*(1), 201–226. doi:10.1146/annurev-environ-031312-102947

Pallot, M. (2009). *The Living Lab Approach: A User Centred Open Innovation Ecosystem. Webergence Blog*. Retrieved from http://www.cwe-projects.eu/pub/bscw.cgi1715404

Panayiotou, C. G., Howell, W. C., & Fu, M. C. (2005). Online traffic light control through gradient estimation using stochastic flow models. In *Proceedings of 2005 IFAC Triennial World Congress*.

Pan, H. (2011). *Implementing sustainable urban travel policies in China*. In *Proceedings of International Transport Forum*. Leipzig, Germany.

Pan, J. G., Lin, Y.-F., Chuang, S.-Y., & Kao, Y.-C. (2011). From governance to service-smart city evaluations in Taiwan. In *Proceedings of International Joint Conference on Service Sciences* (pp. 334-337). doi:10.1109/IJCSS.2011.74

Papa, R., Gargiulo, C., & Galderisi, A. (2013). Towards an urban planners' perspective on smart city. *TeMA - Journal of Land Use*. *Mobility and Environment*, *6*(1), 5–17.

Pappis, C., & Mamdani, E. (1977). A fuzzy logic controller for a traffic junction. *IEEE Transactions on Systems, Man, and Cybernetics*, *7*(10), 707–717. doi:10.1109/TSMC.1977.4309605

Parish, Y. I. H., & Müller, P. (2001). Procedural Modeling of Cities. In *Proceedings of the 28th annual conference on Computer graphics and interactive techniques* (pp. 301-308).

Partridge, H. (2004). *Developing a human perspective to the digital divide in the Smart City*. Retrieved from http://eprints.qut.edu.au/1299/1/partridge.h.2.paper.pdf

Paskaleva, K. (2001). *Innovative partnerships effective governance of sustainable urban tourism*. Retrieved from http://sut.itas.fzk.de/papers/pack1/SUT_Deliverable1_FrameworkApproach.pdf

Patier, D., & Browne, M. (2010). A methodology for the evaluation of urban logistics innovation. *Procedia: Social and Behavioral Sciences*, *2*(3), 6229–6241. doi:10.1016/j.sbspro.2010.04.033

Pedrasa, M. A. A., Spooner, T. D., & MacGill, I. F. (2010). Coordinated Scheduling of Residential Distributed Energy Resources to Optimize Smart Home Energy Services. *IEEE Transactions on Smart Grid*, *1*(2), 134–143. doi:10.1109/TSG.2010.2053053

Pei, G., Gerla, M., & Chen, T. W. (2000). Fisheye state routing: A routing scheme for ad hoc wireless networks. In Communications, 2000. ICC 2000. 2000 IEEE International Conference on (Vol. 1, pp. 70-74). IEEE.

Peng, Z. R., & Lu, Q. C. (2012). *China's public transportation: problems, policies, and prospective of sustainability*. ITE Journal.

Pensa, S., & Masala, E. (2014). InViTo: An Interactive Visualisation Tool to Support Spatial Decision Processes. In N. N. Pinto, J. A. Tenedorio, A. P. Antunes, & J. R. Cladera (Eds.), *Technologies for Urban and Spatial Planning: Virtual Cities and Territories* (pp. 135–153). Hershey, PA: IGI Global Book.

Pensa, S., Masala, E., Lami, I. M., & Rosa, A. (2014). Seeing is knowing: data exploration as a support to planning. *Proceedings of the ICE - Civil Engineering, 167*(5), 3-8.

Pensa, S., Masala, E., & Marina, O. (2013). What if form follows function? The exploration of suitability in the city of Skopje. *Disegnare Con*, *6*(11), 141–148.

Periphèria. (2013). *Policy document*. Retrieved from http://www.peripheria.eu/library/peripheria-policy-document

Petroulias, T. (2014). *Community attitudes to road safety – 2013 survey report*. Melbourne, Australia: Social Research Centre.

Pew Charitable Trusts. (2014). *Who's winning the clean energy race?* Retrieved from http://www.pewtrusts.org/~/media/Assets/2014/04/01/clenwhoswinningthecleanenergyrace2013pdf.pdf

Pick, J. B., & Nishida, T. (2014). Digital divides in the world and its regions: A spatial and multivariate analysis of technological utilization. *Technological Forecasting and Social Change*.

Pierce, W. D., Cameron, J., Banko, K. M., & So, S. (2003). Positive effects of rewards and performance standards on intrinsic motivation. *The Psychological Record*, *53*, 561–579.

Piketty, T. (2014). *Capital in the Twenty-First Century*. Belknap Press.

Pincetl, S., Bunjeb, P., & Holmesc, T. (2012). An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning*, *107*(3), 193–202. doi:10.1016/j.landurbplan.2012.06.006

Polanyi, M. (1958). *Personal Knowledge: Towards a Post Critical Philosophy*. London, UK: Routledge.

Polanyi, M. (1967). *S*ense-giving and sense-reading. *Philosophy: Journal of the Royal Institute of Philosophy*, *42*(162), 301–323. doi:10.1017/S0031819100001509

Poole, A., & Stoner, T. (2003). *Alternative Financing Models for Energy Efficiency Performance Contracting*. The USAID Brazilian Clean and Efficient Energy program. Retrieved from http://www.inee.org.br/down_loads/escos/Alternative Financial Models for EPC.doc

Porche, I., Sampath, M., Sengupta, R., Chen, Y. L., & Lafortune, S. (1996). A decentralized scheme for real-time optimization of traffic signals. In *Proceedings of IEEE International Conference on Control Applications* (pp. 582-589). doi:10.1109/CCA.1996.558925

Porta, S., Latora, V., Wang, F., Strano, E., Cardillo, A., Scellato, S., & Messora, R. et al. (2009). Street centrality and densities of retail and services in Bologna, Italy. *Environment and Planning. B, Planning & Design*, *36*(3), 450–465. doi:10.1068/b34098

Porter, M. E. (1979). How Competitive Forces Shape Strategy. *Harvard Business Review*. PMID:18271320

Portmann, M., & Pirzada, A. A. (2008). Wireless mesh networks for public safety and crisis management applications. *IEEE Internet Computing*, *2*(1), 18–25. doi:10.1109/MIC.2008.25

Portugali, J. (2011). *Complexity Cognition and the City*. Berlin: Springer Heidelberg. doi:10.1007/978-3-642-19451-1

Portugali, J., Meyer, H., Stolk, E., & Tan, E. (Eds.). (2012). *Complexity Theories of Cities Have Come of Age*. Berlin, Heidelberg: Springer. doi:10.1007/978-3-642-24544-2

Posen, A. S. (2003). *It Takes More than a Bubble to Become Japan*. Institute for International Economics.

Prashant, L. A., & Bhatnagar, S. (2011). Reinforcement learning with function approximation for traffic signal control. *IEEE Transactions on Intelligent Transportation Systems*, *12*(2), 412–421. doi:10.1109/TITS.2010.2091408

PRTM. (2011). *The China new energy vehicles program - challenges and opportunities*. Geneva, Switzerland: The World Bank.

Pucher, J., Park, H., Kim, M. H., & Song, J. (2005). Public transport reforms in Seoul: Innovations motivated by funding crisis. *Journal of Public Transportation*, *8*(5), 41–62. doi:10.5038/2375-0901.8.5.3

PwC. (2013). *The Singapore land transport master plan 2013 - A review by PwC*. Singapore: PricewaterhouseCoopers.

Pyrozhenko, V. (2011). Implementing open government: Exploring the ideological links between open government and the free and open source software movement. In *Proceedings of Annual Public Management Research Conference*.

Ra, M.-R., Liu, B., La Porta, T., & Govindan, R. (2012). Medusa: A Programming Framework for Crowd-Sensing Applications. In *Proceedings of 10th International Conference on Mobile Systems, Applications, and Services* (pp. 337-350). doi:10.1145/2307636.2307668

Ramanathan, N., Alquaddoomi, F., Falaki, H., George, D., Hsieh, C., Jenkins, J., & Estrin, D. et al. (2012). ohmage: An open mobile system for activity and experience sampling. In *Proceedings of 6th International Conference on Pervasive Computing Technologies for Healthcare* (pp. 203-204). doi:10.4108/icst.pervasivehealth.2012.248705

Rand, D. A. J., & Dell, R. M. (2001). *Understanding Batteries*. Great Britain: Royal Society of Chemistry.

Ranganathan, K., Ripeanu, M., Sarin, A., & Foster, I. (2003). To share or not to share: An analysis of incentives to contribute in collaborative file sharing environments. In *Proceedings of Workshop on Economics of Peer-to-Peer Systems*.

Rath-Nagel, S., & Voss, A. (1981). Energy models for planning and policy assessment. *European Journal of Operational Research*, *8*(2), 99–114. doi:10.1016/0377-2217(81)90249-6

Raymond, E. (1999). The cathedral and the bazaar. *Knowledge, Technology & Policy*, *12*(3), 23–49. doi:10.1007/s12130-999-1026-0

Rees, W. E. (1997). Is 'sustainable city' an Oxymoron? *Local Environment: The International Journal of Justice and Sustainability*, *2*(3), 303–310. doi:10.1080/13549839708725535

Reinhart, C. M., & Rogoff, K. (2009). *This Time Is Different: Eight Centuries of Financial Folly*. Princeton University Press.

Reix, R. (2000). *Systèmes d'information et management des organisations*. Paris, France: Librairie Vuibert.

Ricquebourg, V., Menga, D., Durand, D., Marhic, B., Delahoche, L., & Christopher, L. (2006). The smart home concept: our immediate future. In *Proceedings of IEEE International Conference on E-Learning in Industrial Electronics* (pp. 18-20). doi:10.1109/ICELIE.2006.347206

Rivers, C. (2002). Coordination in vehicle routing (Doctoral dissertation, Ph. D. thesis, Massey University, Palmerston North, New Zealand).

Robertson, D. I. (1969). TRANSYT method for area traffic control. *Traffic Engineering & Control*, *10*, 276–281.

Roberts, P., & Hughes, S. (2006). *Urban Regeneration: a handbook*. London: Sage Publications.

Robinson, D., Haldi, F., Kämpf, J., Leroux, P., Perez, P., Rasheed, A., & Wilke, U. (2009). CitySim: Comprehensive micro-simulation of resource flows for sustainable urban planning. In *Proceedings of International IBPSA Conference*.

Rockoff, H. (2000). *How Long Did It Take the United States to Become an Optimal Currency Area?* Historical Working Paper 124. The National Bureau of Economic Research.

Rodier, C. J., & Shaheen, S. A. (2010). Transit-based smart parking: An evaluation of the San Francisco bay area field test. *Transportation Research Part C, Emerging Technologies*, *18*(2), 225–233. doi:10.1016/j.trc.2009.07.002

Roos, D. (2010, December 6). Does hybrid car production waste offset hybrid benefits? HowStuffWorks. Retrieved June 14, 2014, from http://science.howstuffworks.com/science-vs-myth/everyday-myths/does-hybrid-car-production-waste-offset-hybrid-benefits2.htm

Rosen, D., Mammano, F., & Favout, R. (1970). An electronic route-guidance system for highway vehicles. *IEEE Transactions on Vehicular Technology*, *19*(1), 143–152. doi:10.1109/T-VT.1970.23442

Rossi, M. (2014). The New Ways to Raise Capital: An Exploratory Study of Crowdfunding. *International Journal of Financial Research*, *5*(2), 8–18. doi:10.5430/ijfr.v5n2p8

Rotmans, J., Van Asselt, M., & Vellinga, P. (2000). An Integrated Planning Tool for Sustainable cities. *Environmental Impact Assessment Review*, *20*(3), 265–276. doi:10.1016/S0195-9255(00)00039-1

Runhaar, H., Driessen, P. P. J., & Soer, L. (2009). Sustainable urban development and the challenge of policy integration: An assessment of planning tools for integrating spatial and environmental planning in the Netherlands. *Environment & Planning B*, *36*(3), 417–431. doi:10.1068/b34052

Sahota, D. (2013). *Deutsche Telekom partners with IBM for Smarter Cities*. Retrieved June 16, 2014, from http://www.telecoms.com/108942/deutsche-telekom-partners-with-ibm-for-smarter-cities/

Sakaki, S. (2012). *TOD in Japan: Experiences and lessons*. Paper presented at second annual meet of the Sustainable Urban Transport Project.

Salat, S. (2011). *Cities and Form: on sustainable urbanism*. Paris, France: Hermann.

Samadi, P., Wong, V. S. V., Schober, R., & Mohsenian-Rad, H. (2011). The Role of Demand Side management. Retrieved June 06, 2014, from http://smartgrid.ieee.org/october-2011/418-the-role-of-demand-side-management

Santos, G., Wai, W. L., & Koh, W. T. H. (2004). Transport policies in Singapore. *Research in Transportation Economics*, *9*, 209–235. doi:10.1016/S0739-8859(04)09009-2

SAP. (2014). *SAP for Public Sector - SAP for State & Local Government*. Retrieved June 16, 2014, from http://global.sap.com/campaigns/2012_08_public_services/state_local_overview.epx

Sarrazin, T. (2012). *Europa braucht den Euro nicht: Wie uns politischesWunschdenken in die Krise geführt hat*. DVA.

Sassen, S. (2001). *The Global City: New York, London, Tokyo*. London: Princeton University Press. doi:10.1515/9781400847488

Sassen, S. (2002). *Global Networks, Linked Cities*. London: Psychology Press.

Satchwell, A. (2010). *A Survey of the US ESCO Industry: Market Growth and Development from 2008 to 2011*. Retrieved from http://escholarship.org/uc/item/2114b1bx

Sato, N. (2003). Advanced Cruise-Assist Highway Systems. *ITS handbook 2002-2003*.

Saunders, D. (2010). *Arrival City: The Final Migration And Our Next World*. London: William Heinemann.

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., & Oliveira, A. (2011). Smart cities and the future Internet: Towards cooperation frameworks for open innovation. In J. Domingue et al. (Eds.), *Future Internet Assembly 2011. Achievements and technological promises* (pp. 431–446). New York: Springer.

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., & Oliveira, A. (2011). Smart Cities and the Future Internet: towards cooperation frameworks for open innovation. In J. Domingue et al. (Eds.), *The Future Internet* (pp. 431–446). Lecture Notes in Computer ScienceSpringer. doi:10.1007/978-3-642-20898-0_31

Schneider-electric. (2014). *Smart Cities*. Retrieved June 16, 2014, from http://www.schneider-electric.com/sites/corporate/en/solutions/sustainable_solutions/smart-cities.page

Schuler, D. (2013). Innovating Democracies. Presentation given at the Smart Communities session of the Smart Cities Exhibition. Bologna, Italy.

Schumpeter, J. ([1939], 1964). Business Cycles: A Theoretical, Historical and Statistical Analysis of Capitalist Process. New York: McGraw-Hill.

Sclafani, A. (2008). The Role of Energy Service Companies in Accelerating Solar Technology To Market. *Strategic Planning for Energy and the Environment*, *28*(2), 24–35. doi:10.1080/10485230809509191

Seisdedos, G. (2012). ¿Qué es una Smart City? *BIT Numerical Mathematics*, *188*, 35–37.

Seltzer, E., & Mahmoudi, D. (2013). Citizen participation, open innovation, and crowdsourcing challenges and opportunities for planning. *Journal of Planning Literature*, *28*(1), 3–18. doi:10.1177/0885412212469112

Sen, S., & Head, L. (1997). Controlled optimization of phases at an intersection. *Transportation Science*, *31*(1), 5–17. doi:10.1287/trsc.31.1.5

SERCO Institute. (2012). *Frugal Innovation. Learning from Social Entrepreneurs in India*. Retrieved from http://www.serco.com/Images/FrugalInnovation_tcm3-39462.pdf

Serrao, L., Onori, S., Sciarretta, A., Guezennec, Y., & Rizzoni, G. (2011, June). Optimal energy management of hybrid electric vehicles including battery aging. In *American Control Conference (ACC)*, 2011 (pp. 2125-2130). IEEE. doi:10.1109/ACC.2011.5991576

SFPark. (2012). *Parking sensor data feed specification*. Retrieved from http://sfpark.org

Shade of Green. (2014, May 4) Shade of Green: Electric Cars' Carbon Emissions Around the Globe. Shrink that Footprint. Retrieved May 4, 2014, from http://shrinkthatfootprint.com/wp-content/uploads/2013/02/Shades-of-Green-Full-Report.pdf

Shah, J., Nielsen, M., Reid, A., Shane, C., Mathews, K., Doerge, D., . . . Sarkar, S. (2014, March). Cost-optimal, robust charging of electrically-fueled commercial vehicle fleets via machine learning. In Systems Conference (SysCon), 2014 8th Annual IEEE (pp. 65-71). IEEE. doi:10.1109/SysCon.2014.6819237

Sharpf, F. W. (2013). *Political Legitimacy in a Non-optimal Currency Area*. MPIfG Discussion Paper 13/15. Köln, Max Planck Institute for the Study of Societies.

Shelby, S. G., Bullock, D. M., Gettman, D., Ghaman, R. S., Sabra, Z. A., & Soyke, N. (2008). Overview and performance evaluation of ACS Lite - a low cost adaptive signal control system. In *Proceedings of 87th Annual Meeting of the Transportation Research Board*.

Shepard, M., & Greenfield, A. (2007). *Situated technologies pamphlet 1: Urban computing and its discontents*. New York: The Architectural League of New York.

Shiffer, M. (1992). Towards a collaborative planning system. *Environment and Planning. B, Planning & Design*, *19*(6), 709–722. doi:10.1068/b190709

Shimokawa, M., & Tezuka, T. (2014). Development of the "Home Energy Conservation Support Program" and its effects on family behavior. *Applied Energy*, *114*, 654–662. doi:10.1016/j.apenergy.2013.10.007

Shoup, D. (2005). *The high cost of free parking*. Chicago, IL: APA Planner Press.

Sieber, R. (2000). GIS implementation in the grassroots. *URISA Journal*, *12*, 15–29.

Siemens. (2009). *European Green City Index*. Retrieved from http://www.thecrystal.org/assets/download/European-Green-City-Index.pdf

Siemens. (n.d). *Infrastructure & Cities - Sustainable Cities*. Retrieved June 16, 2014, from http://w3.siemens.com/topics/global/en/sustainable-cities/Pages/home.aspx

Simon, H. A. (1969). *The Sciences of the Artificial*. Cambridge, MA: MIT Press.

Singapore Land Transport Authority. (2008). Land Transport Masterplan 2008: A people centered land transport system.

Singapore Road Safety Council. (2013). *Towards safer roads in Singapore*.

Singapore Traffic Police. (2012). *STCars anti drink drive campaign 2012*. Singapore: Singapore Traffic Police.

Singh, R. (1999). Sketching the city: A GIS-based approach. *Environment and Planning. B, Planning & Design*, *26*(3), 455–468. doi:10.1068/b260455

SIS. (2013). *Mapping the Crowd, The Lord Mayors Show, SIS Software*. Retrieved from http://www.sis.software.co.uk/

Skoplaki, E., & Palyvos, J. A. (2009). On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar Energy*, *83*(5), 614–624. doi:10.1016/j.solener.2008.10.008

Smart Governance Network. (n.d.). Retrieved June 16, 2014, from http://www.smartgovernance.net/smartdynamic/dynamic_default.asp?id=1

Smith, D. (2014, June 9). Elon Musk May Give Away Its Tesla Supercharger Patents To Spur Electric Car Development. Business Insider. Retrieved June 14, 2014, from http://www.businessinsider.com/elon-musk-tesla-supercharger-patents-2014-6

Smith, H. (2007). Universities, innovation, and territorial development: A review of the evidence. *Environment and Planning C*, *23*(1), 98–114. doi:10.1068/c0561

Soder, L., Hofmann, L., Orths, A., Holttinen, H., Wan, Y. H., & Tuohy, A. (2007). Experience from wind integration in some high penetration areas. *IEEE Transactions on Energy Conversion*, *22*(1), 4–12. doi:10.1109/TEC.2006.889604

Sohraby, K., Minoli, D., & Znati, T. (2007). *Wireless Sensor Networks: Technology, Protocols, and Applications*. Wiley. doi:10.1002/047011276X

Sommer, C., Schmidt, A., Chen, Y., German, R., Koch, W., & Dressler, F. (2010). On the Feasibility of UMTS-based Traffic Information Systems. *Ad Hoc Networks*, *8*(5), 506–517. doi:10.1016/j.adhoc.2009.12.003

Souza Santos, A., & Kahn Ribeiro, S. (2013). The use of sustainability indicators in urban passenger transport during the decision-making process: The case of Rio de Janeiro, Brazil. *Current Opinion in Environmental Sustainability*, *5*(2), 251–260. doi:10.1016/j.cosust.2013.04.010

Spall, J. C., & Chin, D. (1997). Traffic-responsive signal timing for system wide traffic control. *Transportation Research Part C, Emerging Technologies*, *5*(3), 153–163. doi:10.1016/S0968-090X(97)00012-0

Spataru, C. (2013). Energy: Centralisation versus Decentralisation in Global Systems. Science Orientation Paper. Retrieved from http://publications.lib.chalmers.se/records/fulltext/190487/local_190487.pdf

Spataru, C., & Barrett, M. (2015) DEAM: A Scalable Dynamic Energy Agents Model for Demand and Supply, UKSim 2015 – 17th International Conference on Mathematical/Analytical Modelling and Computer Simulation, Cambridge, UK, March 2015

Spataru, C., & Barrett, M. (2012). The Smart Super-European grid: Balancing demand and supply. In *Proceedings of IEEE PES Innovative Smart Grid Technologies Europe*. Berlin.

Stanica, R., Fiore, M., & Malandrino, F. (2013). Offloading Floating Car Data. In *Proceedings of IEEE WoWMoM*.

State of Green. (n.d.). *Smart Energy City, Copenhagen*. Retrieved June 16, 2014, from https://stateofgreen.com/en/profiles/ramboll/solutions/smart-cities-1

Sterling, B. (2005). *Shaping Things*. Cambridge, MA: MIT Press.

Steventon, A., & Wright, S. (Eds.). (2006). *Intelligent Spaces: The Application of Pervasive ICT*. London: Springer-Verlag. doi:10.1007/978-1-84628-429-8

Stiglitz, J. E. (2012a). Rent Seeking and Making of an Unequal Society. In *The Price of Inequality: How Today's Divided Society Endangers Our Future*. W.W. Norton & Company.

Stiglitz, J. E. (2012b). A Macroeconomic Policy and a Central Bank by and for the 1 percent. In *The Price of Inequality: How Today's Divided Society Endangers Our Future*. W.W. Norton & Company.

Stolarick, K., & Florida, R. (2006). Creativity, connectivity and connections: The case of Montreal. *Environment & Planning A*, *38*, 1779–1817.

Streeck, W. (2013). *The Politics of Public Debt. Neoliberalism, Capitalist Development and the Restructuring of the State*. MPIfG Discussion Paper 13/7. Köln: Max Planck Institute for the Study of Societies.

Streetline (2012). *Streetline: Connecting the Real World*. Retrieved from http://www.streetlinenetworks.com

Strzalka, A., Bogdahn, J., Coors, V., & Eicker, U. (2011). 3D City modeling for urban scale heating energy demand forecasting. *HVAC&R Research, 17*(4), 526–539.

Sullivan, A., & Sheffrin, S. M. (2003). *Economics: Principles in action*. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Summerfield, A. J., Lowe, R. J., & Oreszczyn, T. (2010). Two models for benchmarking UK domestic delivered energy. *Building Research and Information*, *38*(1), 12–24. doi:10.1080/09613210903399025

Summers, L. H. (2013). Economic Possibilities for Our Children. NBER Reporter (4), 1-6. The National Bureau of Economic Research.

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable & Sustainable Energy Reviews*, *13*(8), 1819–1835. doi:10.1016/j.rser.2008.09.033

Swan, M. (2012). Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0. *Journal of Sensor and Actuator Networks*, *1*(3), 217–253. doi:10.3390/jsan1030217

Swanson, T. (2014). *Great chain of numbers: a Guide to Smart Contracts, Smart Property and Trustless Asset Management*. Amazon Digital Services, Inc.

Symantec. (2014). *Transformational 'smart cities': cyber security and resilience*. Symantec. Retrieved June 16, 2014 from https://eu-smartcities.eu/sites/all/files/blog/files/Transformational%20Smart%20Cities%20-%20Symantec%20Executive%20Report.pdf

Taft, D. (2013). *IBM, Deutsche Telekom Team on Smarter Cities Effort*. Retrieved June 16, 2014, from http://www.eweek.com/enterprise-apps/ibm-deutsche-telekom-team-on-smarter-cities-effort/

Taipei City Government. (2010). *Taipei yearbook 2009*. Taipei: Taipei City Government.

Takamine, Y. (2004). *Infrastructure services and social inclusion of persons with disabilities and older persons in East Asia and the Pacific*.

Tan, J. K., Stolz, D. R., & Mijan, S. (2003). *Safe to build and safe to use – a total safety management system*. Paper presented at Rail Transit System Conference, Singapore.

Tan, Z. (2012). New transport plan driven by technology. *China Daily*.

Tauber, L. A. (1995, October). Viability and economics of building or purchasing, driving, and maintaining an electric car. In Northcon 95. I EEE Technical Applications Conference and Workshops Northcon95 (pp. 400-405). IEEE. doi:10.1109/NORTHC.1995.485104

te Brömmelstroet, M. C., Silva, C., & Bertolini, L. (2014). *COST Action TU1002 - Assessing Usability of Accessibility Instruments.* Retrieved November 30, 2014, from http://www.accessibilityplanning.eu/wp-content/uploads/2014/05/COST-REPORT-II.pdf

te Brömmelstroet, M. C. (2010). Equip the warrior instead of manning the equipment: Land use and transport planning support in the Netherlands. *Journal of Transport and Land Use*, *3*, 25–41.

Telecom Italia Corporate. (2013). *Socio-environmental telecommunications solutions*. Retrieved June 16, 2014, from http://www.telecomitalia.com/tit/en/innovation/hot-topics/scenarios/smart-services.html

Telefonica. (n.d.). *Sustainability*. Retrieved June 16, 2014, from http://www.crandsustainability.telefonica.com/en

Teodorovic, D., & Lucic, P. (2006). Intelligent parking systems. *European Journal of Operational Research*, *175*(3), 1666–1681. doi:10.1016/j.ejor.2005.02.033

The Climate Group. (2008). *Smart 2020*. Global e-Sustainability Initiative. Retrieved June 16, 2014 from http://www.smart2020.org/_assets/files/02_smart2020Report.pdf

The Copenahagen Wheel. (2014). Retrieved November 30, 2014, from http://senseable.mit.edu/copenhagenwheel

Thompson, B. (2012). *Local Asset Backed Vehicles. A success story or unproven concept?* London: RICS.

Thompson, R. G., & Bonsall, P. (1997). Driver's response to parking guidance and information systems. *Transport Reviews*, *17*(2), 89–104. doi:10.1080/01441649708716974

Thompson, R. G., & Richardson, A. J. (1998). A parking search model. *Transportation Research*, *33*, 159–170.

Toke, D. (2005). Community wind power in Europe and in the UK. *Multi Science Publishing Journal on Wind Engineering*, *29*(3), 301–308.

Tommis, M., & Decorme, R. (2013). *ICT Roadmap for Energy Efficient Neighbourhoods*. Retrieved May 03, 2014, from http://www.ireenproject.eu/wp-content/uploads/2011/11/eChallenges2012_fullpaper_final.pdf

TomTom. (2010). Travel Time Measurements using GSM and GPS Probe Data. In *Proceedings of 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services*. Stockholm, Sweden

Tonchia, S., & Tramontano, A. (2004). *Process Management for the Extended Enterprise*. Berlin: Springer Verlag. doi:10.1007/978-3-642-17051-5

Toshiba. (n.d.). *Smart Community*. Retrieved June 16, 2014, from http://www.toshiba-smartcommunity.com/EN/

Townsend, A. (2013). *Smart cities: Big data, civic hackers, and the quest for a new utopia*. New York: W. W. Norton & Company, Inc.

Townsend, A. M. (2013). *Smart cities: big data, civic hackers, and the quest for a new utopia*. New York, NY: WW Norton & Company.

Toyota (2014). Toyota's philosophy for a safe vehicle. *Safety Technology*. Japan: Toyota Technology File.

Tozlu, S., Senel, M., Mao, W., & Keshavarzian, A. (2012). Wi-Fi enabled sensors for Internet of Things: A practical approach. *IEEE Communications Magazine*, *50*(6), 134–143. doi:10.1109/MCOM.2012.6211498

Transdev (2014). The Hong Kong Tramway, operated since April 2009 by the Transdev RATPDev joint venture, Hong Kong Tramways, is celebrating its 110th anniversary. *Transdev*. Retrieved from http://www.transdev.com/en/media/press-releases/1166.htm

TransportPolicy.net. (2013). *South Korea: light-duty: emissions*. Retrieved from http://transportpolicy.net/index.php?title=South_Korea:_Light-duty:_Emissions

Tratz-Ryan, B., Di Maio, A., Velosa, A., & Nakano, N. (2012). *Innovation Insight: smart city Aligns Technology Innovation and Citizen Inclusion*. Gartner Inc. Retrieved June 16, 2014 from https://www.gartner.com/doc/2286119/innovation-insight-smart-city-aligns

Trivellato, B., Cavenago, D., & Beltrami, G. (2013). Is strategic urban planning becoming 'smarter'? Reflections on a selection of European cities". In *Proceedings of EGPA Annual Conference*.

Tsai, M., & Chu, C. (2012). Evaluating parking reservation policy in urban areas: An environmental perspective. *Transportation Research Part D, Transport and Environment*, *17*(2), 145–148. doi:10.1016/j.trd.2011.10.006

Tse, D., & Viswanath, P. (2005). *Fundamentals of wireless communication*. Cambridge University Press. doi:10.1017/CBO9780511807213

Tseng, Y.-C., Hsu, C.-S., & Hsieh, T.-Y. (2002). Power-saving protocols for IEEE 802.11-based multi-hop ad hoc networks. In Proceedings of IEEE INFOCOM.

Tsuchiya, S. (1993). Improving knowledge creation ability through organizational learning. In *Proceedings of the International Symposium on the Management of Industrial and Corporate Knowledge* (pp. 87–95).

Tsuda, M., Hara, M., Nemoto, Y., & Nakamura, J. (2007). Gross Social Feel-good Index – Social Impact Assessment for ICT Services. *NTT Technical Review*, *5*(3). Retrieved from https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200703043.pdf

Tunaru, I., Rivano, H., & Valois, F. (2013). WSN-inspired Sleep Protocols for Heterogeneous LTE Networks. In *Proceedings of PE-WASUN*. doi:10.1145/2507248.2507267

Tyco Traffic & Transportation. (2014). *SCATS, urban traffic control*. Australia: Tyco Traffic & Transportation.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2010, November). Electric Power Monthly. Retrieved June 14, 2014, from http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html

Uhlig, H. (2008). The Slow Decline of East Germany. *Journal of Comparative Economics*, *36*(4), 517–541. doi:10.1016/j.jce.2008.07.006

United Nations Development Policy and Analysis Division. (2013). *World Economic and Social Survey 2013 - Sustainable Development Challenges*.

United Nations Economic and Social Affairs. (2012). *World Urbanization Prospects. The 2011 Revision*.

United Nations Human Settlements Programme. (2004). *Urban Indicators Guidelines: Monitoring the Habitat Agenda and the Millennium Development Goals.* Retrieved November, 30, 2014, from http://ww2.unhabitat.org/programmes/guo/documents/urban_indicators_guidelines.pdf

United Nations Human Settlements Programme. (2006). *State of the World's Cities 2006/7. The Millennium Development Goals and Urban Sustainability: 30 Years of Shaping the Habitat Agenda*. Retrieved November, 30, 2014 from http://sustainabledevelopment.un.org/content/documents/11292101_alt.pdf

United Nations. (2007). Indicators of sustainable development: Guidelines and methodologies. Retrieved November, 30, 2014, from http://www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf

United Nations. (2008). *Guidebook on promoting good governance in public-private partnership*. Retrieved from http://www.unece.org/fileadmin/DAM/ceci/publications/ppp.pdf

United Nations. (2013). *World Economic and Social Survey 2013, Sustainable Development Challenges*. Retrieved June 16, 2014 from https://sustainabledevelopment.un.org/content/documents/2843WESS2013.pdf

Uppoor, S., Trullols-Cruces, O., Fiore, M., & Barcelo-Ordinas, J. M. (2014). Generation and Analysis of a Large-scale Urban Vehicular Mobility Dataset. *IEEE Transactions on Mobile Computing*, *13*(5), 1061–1075. doi:10.1109/TMC.2013.27

Uran, O., & Janssen, R. (2003). Why are spatial decision support systems not used? Some experiences from the Netherlands. *Computers, Environment and Urban Systems*, *27*(5), 511–526. doi:10.1016/S0198-9715(02)00064-9

Urban Europe, J. P. I. (2013). *Call for Proposals*. Retrieved from http://www.jpi-urbaneurope.eu/dsresource?objectid=329044&type=org

Urry, J. (2012). Changing transport and changing climates. *Journal of Transport Geography*, *24*, 533–535. doi:10.1016/j.jtrangeo.2012.05.005

USB Implementers Forum. (2010). *Wireless USB Specification Revision 1.1*.

Valdimarsson, P. (1993). *Modelling of geothermal district heating systems*. (Doctoral dissertation). University of Iceland, Rejkavik.

Van Dam, K., & Keirstead, J. (2010). Re-use of an ontology for modelling urban energy systems. In *Proceedings of Third International Conference on Infrastructure Systems and Services: Next Generation Infrastructure Systems for Eco-Cities*. doi:10.1109/INFRA.2010.5679232

VDE. (2014). *The German Standardization Roadmap Smart City* [Die Deutsche Normungs-Roadmap Smart City]. Frankfurt: VDE Verband der Elektrotechnik Elektronik Informationstechnik.

Veirier, L. (2008). *Historic districts for all: a social and human approach for sustainable revitalization*. Retrieved November, 30, 2014, from http://unesdoc.unesco.org/images/0017/001784/178420e.pdf

Verilhac, I., Pallot, M., & Aragall, F. (2012). IDeALL: Exploring the Way to Integrate Design for All within Living Labs. In *Proceedings of the 18th International Conference on Engineering, Technology and Innovation*. Munich, Germany. doi:10.1109/ICE.2012.6297699

Veron, J. (2006). *L'urbanisation du monde*. Paris: La Découverte.

Viitanen, J., & Kingston, R. (2014). Smart cities and green growth: Outsourcing democratic and environmental resilience to the global technology sector. *Environment & Planning A*, *46*(4), 803–819. doi:10.1068/a46242

Villa, N., & Wagener, W. (2008). Connecting Cities: Achieving Sustainability through Innovation – an overview of the connected urban development program.*InProceedings of CISCO's Connected Urban Development Global Conference*.

Vinci, I., & Di Dio, S. (2014). Designing mobility in a city transition: Challenge from the case of Palermo. *Journal of Land Use, Mobility and Environment*, 978-988.

Vine, E. (2005). An international survey of the energy service company (ESCO) industry. *Energy Policy*, *33*(5), 691–704. doi:10.1016/j.enpol.2003.09.014

Vonk, G. (2006). *Improving planning support; the use of planning support systems for spatial planning*. Utrecht: Nederlandse Geografische Studies.

Waddell, P. (2000). A behavioral simulation model for metropolitan policy analysis and planning: Residential location and housing market components of UrbanSim. *Environment and Planning. B, Planning & Design*, *27*(2), 247–263. doi:10.1068/b2627

Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M., & Ulfarsson, G. (2003). *Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim*. Netherlands: Springer.

Wagner, R. S. (2010). Standards-based wireless sensor networking protocols for spaceflight applications. In *Proceedings of IEEE Aerospace Conference*. doi:10.1109/AERO.2010.5446672

Walsham, G. (2001). Knowledge management: The benefits and limitations of computer systems. *European Management Journal*, *19*(5), 599–608. doi:10.1016/S0263-2373(01)00085-8

Wamsler, C., & Brink, E. (2014). Interfacing citizens' and institutions' practice and responsibilities for climate change adaptation. *Urban Climate*, *7*, 64–91. doi:10.1016/j.uclim.2013.10.009

Wang, H., Song, Y., Hamilton, A., & Curwell, S. (2007). Urban information integration for advanced e-planning in Europe. *Government Information Quarterly*, *24*(4), 736–754. doi:10.1016/j.giq.2007.04.002

Want, R., & Pering, T. (2005). System challenges for ubiquitous & pervasive computing. In *Proceedings of ACM International conference on Software engineering* (pp. 9-14).

Wardi, Y., Adams, R., & Melamed, B. (2010). A unified approach to infinitesimal perturbation analysis in stochastic flow models: The single-stage case. *IEEE Transactions on Automatic Control*, *55*(1), 89–103. doi:10.1109/TAC.2009.2034228

Washburn, D., & Sindhu, U. (2010). *Helping CIOs Understand "Smart City" Initiatives*. Retrieved from http://www.uwforum.org/upload/board/forrester_help_cios_smart_city.pdf

Waterson, B. J., Hounsellm, N. B., & Chatterjee, K. (2001). Quantifying the potential savings in travel time resulting from parking guidance systems - a simulation case study. *The Journal of the Operational Research Society*, *52*(10), 1067–1077. doi:10.1057/palgrave.jors.2601207

Webb, M., Finighan, R., Buscher, V., Doody, L., Cosgrave, E., Giles, S., . . . Mulligan, C. (2011). *Information marketplaces, the new economics of cities*. Report from The Climate Group, Arup, Accenture and Horizon, University of Nottingham. Retrieved from http://www.theclimategroup.org/what-we-do/publications/Information-Marketplaces-The-New-Economics-of-Cities/

Weber, M. (1978). *Economy and Society*. University of California Press.

Wegener, M. (1994). Operational Urban Models State of the Art. *Journal of the American Planning Association*, *60*(1), 17–29. doi:10.1080/01944369408975547

Wegener, M. (1995). Current and Future Land Use Models. In *Proceedings of Land Use Model Conference*. Texas.

Wen, W., & Hsu, H. W. (2006). A dynamic and automatic traffic light control system for solving the road congestion problem. *WIT Transactions on the Built Environment*, *89*, 307–316.

Wen, Y., & Wu, T. (2005). Reduced-order rolling horizon optimization of traffic control based on ant algorithm. [Engineering Science]. *Journal of Zhejiang University*, *39*(6), 835–839.

Weyn, M., Ergeerts, G., Wante, L., Vercauteren, C., & Hellinckx, P. (2013). Survey of the DASH7 Alliance protocol for 433 MHz wireless sensor communication. *International Journal of Distributed Sensor Networks*, *2013*, 1–9. doi:10.1155/2013/870430

Wey, W. M. (2000). Model formulation and solution algorithm of traffic light control in an urban network. *Computers, Environment and Urban Systems*, *24*(4), 355–377. doi:10.1016/S0198-9715(00)00002-8

White, R., & Engelen, G. (1997). Cellular automata as the basis of integrated dynamic regional modelling. *Environment and Planning. B, Planning & Design*, *24*(2), 235–246. doi:10.1068/b240235

White, R., & Engelen, G. (2000). High-resolution integrated modelling of the spatial dynamics of urban and regional systems. *Computers, Environment and Urban Systems*, *24*(5), 383–400. doi:10.1016/S0198-9715(00)00012-0

Wiechmann, H. (2008). Neue Betriebsführungsstrategien für unterbrechbare Verbrauchseinrichtungen: ein Modell für eine markt- und erzeugerorientierte Regelung der Stromnachfrage über ein zentrales Lastmanagement. Karlsruhe

Wiering, M., Vennen, J., & Koopman, A. (2004). *Intelligent traffic light control*. Retrieved from http://dspace.library.uu.nl/handle/1874/17996

Wi-Fi Alliance. (2014). *Wi-Fi Peer-to-Peer (P2P) Technical Specifications v1.5*.

Wilson, T. (2002). The nonsense of 'knowledge management'. *Information Research, 8*(1).

Wispes srl. (2010). *Wireless energy autonomous meters*. Retrieved from http://wispes.com/

Wolfram, S. (1984). Cellular automata as model of complexity. *Nature*, *311*(5985), 419–424. doi:10.1038/311419a0

Wood, A. J., & Wollenberg, B. F. (2012). *Power generation, operation, and control*. New York, NY: John Wiley & Sons.

World Bank. (2015). *Community-driven development overview.* Retrieved from http://www.worldbank.org/en/topic/communitydrivendevelopment/overview

World Commission on Environment and Development (WCED). (1987). *Our common future*. Oxford, UK: Oxford University Press.

World Health Organization. (1997). *Measuring Quality of Life*. World Health Organization. Retrieved June 16, 2014 from http://www.who.int/mental_health/media/68.pdf

World Health Organization. (2009). *Global status report on road safety: time for action*. Geneva, Switzerland: World Health Organization.

World Health Organization. (2011). *Road safety in China*. Geneva, Switzerland: World Health Organization.

Worley, O., & Klabjan, D. (2011, September). Optimization of battery charging and purchasing at electric vehicle battery swap stations. In *Vehicle Power and Propulsion Conference (VPPC)*, 2011IEEE (pp. 1-4). IEEE. doi:10.1109/VPPC.2011.6043182

Wosley, L. A. (1998). *Integer Programming*. New Jersey: John Wiley and Sons Inc.

Wu, H. H., Gilchrist, A., Sealy, K., Israelsen, P., & Muhs, J. (2011, May). A review on inductive charging for electric vehicles. In Electric Machines & Drives Conference (IEMDC), 2011 IEEE International (pp. 143-147). IEEE. doi:10.1109/IEMDC.2011.5994820

Wu, J., Sui, Y., & Wang, T. (2009). Intelligent transport systems in China. In *Proceedings of the ICE - Municipal Engineer.*

Xiping, H., Chu, T. H. S., Chan, H. C. B., & Leung, V. C. M. (2013). Vita: A Crowdsensing-Oriented Mobile Cyber-Physical System. *IEEE Transactions on Emerging Topics in Computing*, *1*(1), 148–165. doi:10.1109/TETC.2013.2273359

Yan, T., Marzilli, M., Holmes, R., Ganesan, D., & Corner, M. (2009). mCrowd: a platform for mobile crowdsourcing. In *Proceedings of 7th ACM Conference on Embedded Networked Sensor Systems* (pp. 347-348).

Yilmaz, M., Buyukdegirmenci, V. T., & Krein, P. T. (2012, June). General design requirements and analysis of roadbed inductive power transfer system for dynamic electric vehicle charging. In *Transportation Electrification Conference and Expo (ITEC)*, 2012IEEE (pp. 1-6). IEEE. doi:10.1109/ITEC.2012.6243497

Young, W., Thompson, R., & Taylor, M. (1991). A review of urban car parking models. *Transport Reviews*, *11*(1), 63–84. doi:10.1080/01441649108716773

Zeifman, M., & Roth, K. (2011). Nonintrusive appliance load monitoring: Review and outlook. *IEEE Transactions on Consumer Electronics*, *57*(1), 76–84. doi:10.1109/TCE.2011.5735484

Zhang, W., Wong, S. C., Tse, C. K., & Chen, Q. (2011, September). A study of sectional tracks in roadway inductive power transfer system. In Energy Conversion Congress and Exposition (ECCE), 2011 IEEE (pp. 822-826). IEEE. doi:10.1109/ECCE.2011.6063855

Zhang, W., Wong, S., Tse, C., & Chen, Q. (2014). An Optimized Track Length in Roadway Inductive Power Transfer Systems. *Emerging and Selected Topics in Power Electronics, IEEE Journal of, 99*.

Zhang, J., Orlik, P. V., Sahinoglu, Z., Molisch, A. F., & Kinney, P. (2009). UWB Systems for Wireless Sensor Networks. *Proceedings of the IEEE*, *97*(2), 313–331. doi:10.1109/JPROC.2008.2008786

Zhao, X., & Chen, Y. (2003). Traffic light control method for a single intersection based on hybrid systems. In *Proceedings of IEEE International Conference on Intelligent Transportation Systems* (pp. 1105-1109).

Zhu, H. (2005). *The importance of property markets for monetary policy and financial stability. Real estate indicators and financial stability, 21* (pp. 9–29). Bank for International Settlements.

Zhu, H., Li, M., Zhu, Y., & Ni, L. M. (2009). Hero: Online real-time vehicle tracking. *IEEE Transactions on Parallel and Distributed Systems*, *20*(5), 740–752. doi:10.1109/TPDS.2008.147

Zigbee Alliance. (2008). *Zigbee specifications.* ZigBee Document 053474r17.

ZSW engineers build lithium-ion battery able to last for 27 years. (n.d.). *ZSW engineers build lithium-ion battery able to last for 27 years*. Retrieved June 14, 2014, from http://phys.org/news/2013-06-zsw-lithium-ion-battery-years.html

Zweben, M., & Fox, M. S. (1994). *Intelligent Scheduling*. San Francisco, CA: Morgan Kaufmann Publishers.

About the Contributors

Andrea Vesco received the M.Sc. degree in Telecommunication Engineering and the Ph.D. in Computer and System Engineering from the Politecnico di Torino in 2003 and 2009 respectively. After one year of post-doc with the Control and Computer Engineering Department as a member of the Computer Networks Group at the Politecnico di Torino, he joined the Networking Lab at the Istituto Superiore Mario Boella (ISMB) in 2010. His research interests were on Quality-of-Service (QoS) over packet switched networks and wireless access networks. Moreover he carried out research activities on QoS over Network-on-Chip (NoC). After ten years of experience and several publications in the networking field, He had the opportunity to focus his researches on the Smart City subject in 2013. His research effort is currently spent on the role of ICT in planning, developing and managing Smart Cities, with particular focus on sustainable mobility and energy efficiency.Finally, he is a member of the IEEE and of the Smart City Stakeholder Platform EU (http://www.eu-smartcities.eu).

Francesco Ferrero holds a master's degree summa cum laude in Physics from the University of Turin. Since February 2012 he is heading the Smart City Strategic Program for Istituto Superiore Mario Boella (ISMB). Between 2010 and 2012 Francesco was responsible for ISMB of the Innovation Front End, a joint unit with the Politecnico di Torino in charge of technology transfer, knowledge management and relationship with businesses. From 2007 to 2010 he was a researcher and analyst in the Laboratory of Applied Banking Technology (a joint initiative of ISMB and the Intesa Sanpaolo bank), working on various R&D and technology intelligence projects in the fields of process transformation, customer experience and mobile payments & services. From 2005 to 2007 he was a researcher in the e-security laboratory, mainly with a focus on: P2P protocols, protection of critical infrastructures, encryption in embedded devices, security of routing protocols and activities of dematerialization for the PA. Francesco is a member of the ICT4Smart Cities working group of the Smart Cities Stakeholder Platform (http://www.eu-smartcities.eu/ict_group) and of the World Smart Capital International Steering Committee (www.worldsmartcapital.net). He was a member of the jury of the Torino Startup Weekend (torino.startupweekend.org) in 2012 and 2013.

* * *

Giorgio Agugiaro has studied in environmental engineering at the University of Padova (Italy). In 2009 he received his Ph.D. in Geomatics as a joint doctorate between the Technische Universität Berlin and the University of Padova. His main research topics are 3D Geographical Information Systems (GIS) and spatial data integration, with particular focus on virtual city modelling and their energy-related topics. Before joining AIT in March 2014, he worked as independent consultant at the Fondazione Bruno Kessler (Trento, Italy) in the 3D Optical Metrology unit. In 2013 he spent 7 months as visiting researcher at the Technische Universität München (Germany) where he focused primarily on energy simulations tools tied to 3D virtual city models.

Roger N. Anderson is Senior Scientist at the Center for Computational Learning Systems (CCLS) in the Fu School of Engineering and Applied Science (SEAS) and Adjunct Professor at the Department of Earth and Environmental Sciences at Columbia University. In his 40 years at Columbia, he is the inventor of 27 Patent applications and counting (14 granted so far), and has written 5 books, edited 4 others, and published 215+ peer-reviewed scientific papers, 52 editorially-reviewed papers, and 14 video productions. For 32 years, Roger has taught "Planet Earth" a part of the famous Columbia College core curriculum, and as the last resort science-requirement to graduation, it is one of the most popular courses at Columbia. He has graduated 9 Ph.D. students, many of whom are leaders in the scientific and business communities. Roger is also Principal Investigator of a team of 10+ scientists, engineers, and graduate students in Computer Sciences and Operations Research at Columbia that are developing the next generation of intelligent control systems for Smart City infrastructure (electricity, water, steam, electric fleet vehicles, skyscrapers, microgrids).

Walid Bechkit is an assistant professor with the Telecommunications department at INSA de Lyon. He is also a member of the INRIA UrbaNet team of the CITI laboratory. He obtained his Ph.D. in System and Information Technology from the Compiegne University of Technology (U.T.C.) in 2012 and his engineering degree in Computer Science from the National School of Computer Science of Algiers (ESI) in 2009. His main research interests include energy saving, deployment, reliability and security issues in wireless sensor networks.

Isabelle Augé-Blum is an associate professor in the Telecommunications department at INSA Lyon, and a researcher within the CITI laboratory, working in the Inria Urbanet research group. In 2000, she received her Ph.D. in Computer Science, from the University of Toulouse, on quality of service for industrial networks. Her research interests take place in the area of wireless sensor networks and more particularly on real-time protocols, formal verification and validation.

Brigitte Bach is authorized representative of the AIT - Austrian Institute of Technology and Head of the AIT Energy Department, where she is responsible for strategic development, personnel and finances. Brigitte Bach obtained her PhD in Engineering Physics from the Vienna University of Technology in 1992 and completed a postgraduate degree in Management Development and Communication at the Danube University Krems. She started her career at AIT in 1999 and was appointed Head of the Energy Department in January 2009. Brigitte Bach is actively involved in national and international bodies. She is a member of the EERA (European Energy Research Alliance) Executive Committee, Coordinator of the Joint Programme on Smart Cities and Chair of the group "Horizon 2020 Advisory Group on Energy". Moreover she acts as a chair of the extern Expert Group for "Smart City Vienna". Brigitte Bach received the "Austrian of the Year 2009" award in the category "Research" in autumn 2009.

Daniele Basciotti is working at AIT - Austrian Institute of Technology (former arsenal research), Vienna (Austria) in the business unit Sustainable Thermal Energy Systems since August 2008. During his education in Italy (University of Pisa) he mostly dealt with automation and control systems. At AIT he works in the field of modeling and simulation of thermal components of renewable energy systems with a special focus on district heating networks. He is currently working within the IEA EBC Annex 60 on developing new generation computational tools for building and community energy systems. Within the framework of the European project OrPHEuS he is involved in the development and simulation of novel control strategies for cooperative hybrid grids.

Michael Batty is Bartlett Professor of Planning at University College London in the Centre for Advanced Spatial Analysis (CASA) where he is Chair of the Centre for Advanced Spatial Analysis. He has worked on computer models of cities and their visualisation since the 1970s and has published several books, such as Cities and Complexity (MIT Press, 2005) which won the Alonso Prize of the Regional Science Association in 2011, and most recently The New Science of Cities (MIT Press, 2013). His blogs (www.complexcity.info) cover the science underpinning the technology of cities and his posts and lectures on big data and smart cities (www.spatialcomplexity.info).

Paolo Bellavista is an Associate Professor at the University of Bologna, Italy. His research activities span from mobile computing to pervasive ubiquitous middleware, from location/context-aware services to vehicular sensor networks, from big data adaptive stream processing to adaptive and scalable multimedia. He published more than 60 magazine/journal articles and more than 80 conference/workshop papers in those fields, reporting results from several national- and EU-funded projects. He serves on the Editorial Boards of IEEE TC, IEEE TNSM, IEEE TSC, Elsevier PMC, Elsevier JNCA, and Springer JNSM. See also http://lia.deis.unibo.it/Staff/PaoloBellavista/ for additional details and the complete list of publications.

Pierrick Bouffaron received a Master of Science from Ecole Centrale de Nantes with a focus on Energy and Environment (2008) and a Master of Advanced Studies in Economics and Energy Policy from Mines ParisTech (2012), with a dissertation in the field of smart power grids. He is currently working for the French Ministry of Foreign Affairs in San Francisco, in charge of promoting the French Science & Technology with US actors and watching innovations in the Bay Area, while conducting research at UC Berkeley on environmental data processing and analysis for energy-efficient commercial buildings. He has worked in South-East Asia, Australia, Germany, France and the United-States for the last six years. Mr. Bouffaron has experience in energy production and distribution, climate policy, global energy and sustainable development issues.

Albert Boulanger received a B.S. in physics and the University of Florida, Gainesville, Florida USA in 1979 and a M.S, in computer science at the University of Illinois, Urbana-Champaign, Illinois USA in 1984. He is a co-founder of CALM Energy, Inc. and a VP, Director of Technical Strategy, and board member of the nonprofit environmental and social organization, World Team Now and founding member of World Team Building, LLC. He is a Senior Staff Associate at Columbia University's Center for Computational Learning Systems, and before that, at the Lamont-Doherty Earth Observatory. While on leave of absence from Lamont, Albert held the CTO position of the startup vPatch Technologies, Inc.

For the past 19 years at Columbia, Albert has been involved in far reaching energy research and development– in oil and gas and electricity. He is currently a member of a team of 10 scientists and graduate students in Computer Sciences at Columbia who are jointly developing, with Finmeccanica, the Di-Boss smart building solution. His specialties are complex systems integration and intelligent computational reasoning that interacts with humans within large-scale systems.

Khaled Boussetta is associate professor at University Paris 13, France, since September 2004. In September 2012, he joined the CITI lab at INSA Lyon as INRIA sabbatical researcher. He received a master degree in Computer Science from University Paris 6 and a Ph.D. degree in Computer Science from University of Versailles in 1996 and 2003, respectively. He was in 2001 a visiting researcher at the Network Research Lab at UCLA and in 2003 a postdoc researcher at the computer science laboratory (LIP6) at University Paris 6. His present research interests include Wireless Multi-Hops technologies (WSN, Mesh, VANET), Urban networks, ITS, Multimedia and Clouds. He published over than 60 referred journal and conference papers. He is actively involved in the community as a conference chair, TPC member, and a reviewer for many conferences and journals.

Davide Brunelli received the degree M. Sc. in Electrical Engineering (2002) and PhD in Electrical Engineering (2007) from the University of Bologna, Faculty of Electrical Engineering (Italy). In 2010 he joined to University of Trento as Assistant Professor. He has been scientific supervisor of several EU FP7 and H2020 projects. He was leading industrial cooperation activities with Telecom Italia, STMicroelectronics and Hewlett-Packard. He is author of more than 80 papers in international journals and conferences, that have been cited more than 1400 times. Dr. Brunelli is a member of IEEE and participated to several TPC of conferences in the field of sensor networks and energy management, including The Design, Automation, and Test in Europe (DATE) conference and the IEEE Conference on Emerging Technologies and Factory Automation. He was general chair of the Summer School of Future Energy Systems (2011, 2012) and founder of the International Workshop on Energy Neutral Sensing Systems.

Helfried Brunner studied Electrical Engineering and Information Technology, specializing on Power Engineering at the University of Technology Graz and Innovation and Technology Management at the University for Applied Sciences Technikum Vienna. Since 2004 he is at the AIT- Austrian Institute of Technology currently thematic coordinator of the research field Smart Grids. Helfried Brunner is AIT representative of the EERA (European Energy Research Alliance) Joint Program on Smart Grids and Technical Coordinator of the EERA Integrated Research Program ELECTRA. Helfried Brunner is active within the European Electricity Grid Initiative (EEGI) by supporting the member states initiative within EEGI as a national expert. Helfried is further member of board of the National Technology Platform Smart Grids Austria and lecturer in the field of electricity networks at the University of Technology Vienna and the University for Applied Sciences Technikum Vienna.

Gianni Carbonaro after studying economics and urban planning in Italy and the US, worked as a consultant and an academic in the United States, the UK and Italy and joined the European Investment Bank in1987. Research interests and professional experience have covered urban end regional economics, transportation analysis, infrastructure policy, cost-benefit analysis, European transportation networks, housing policy and finance, and the interface between urban development and property markets. At the EIB Mr Carbonaro has worked on the economic and financial assessment of large-scale infrastructure projects in transport (urban transport systems, motorways, railways, toll infrastructure) and urban development. In April 2007 he joined the Bank's JESSICA (Joint European Support for Sustainable Investment in City Areas) Task Force and he is now Head of the Municipal and Regional Unit within the Advisory Services Department. He is also Visiting Professor and Fellow of QASER (Quantitative and Applied Spatial Economic Research) at University College London.

Christos G. Cassandras is Distinguished Professor of Engineering at Boston University, Head of the Division of Systems Engineering, and Professor of Electrical and Computer Engineering. He received degrees from Yale University (B.S., 1977), Stanford University (M.S.E.E., 1978), and Harvard University (S.M., 1979; Ph.D., 1982). In 1982-84 he was with ITP Boston, Inc. where he worked on the design of automated manufacturing systems. In 1984-1996 he was a faculty member at the Department of Electrical and Computer Engineering, University of Massachusetts/Amherst. He specializes in the areas of discrete event and hybrid systems, cooperative control, stochastic optimization, and computer simulation, with applications to computer and sensor networks, manufacturing systems, and transportation systems. He has published over 350 refereed papers in these areas, and five books. Dr. Cassandras was Editor-in-Chief of the IEEE Transactions on Automatic Control from 1998 through 2009 and has served on several editorial boards. He was the 2012 President of the IEEE Control Systems Society and is the recipient of several awards. He is a member of Phi Beta Kappa and Tau Beta Pi. He is also a Fellow of the IEEE and a Fellow of the IFAC.

Barbara Lo Casto was born in Palermo in 1972 His background is in engineering. She graduated at the University of Palermo (Italy) in Civil Engineering and she is a Ph.D. at the University of Palermo in "Technology and Economics of transport." In 2003 she took the post-graduate course in "Techniques of Transport Management" at the University of LIUC Castellanza, Italy. In 2005 she won the Marie Curie Scholarship Program at the Institute for Transport Studies, University of Leeds, UK. From 2008 to 2013 she was research fellow at the Department of Transport Engineering, University of Palermo, on " Intelligent Transport System (ITS) for sustainable urban mobility", and then, until 2014 she was research fellow at the Department of Energy, Information Engineering and Mathematical Models. The main research topics of her academic career are about urban transport demand modelling, environmental impact exerted by transportation systems, Intelligent Transport System, sustainable mobility, Life Cycle Analysis.

Giuseppe Cardone graduated from the University of Bologna, Italy, where he received a Ph.D. degree in in computer engineering in 2013. He is now a research fellow at the same university. His interests include performance and scalability issues of distributed systems, urban mobile sensing, and power-aware middleware solutions.

Hoong-Chor Chin is an associate professor at the national University of Singapore; he has a Ph.D in Transportation Engineering from the University of Southampton. He has published numerous papers on Transportation Modelling, Smart and Sustainable Transportation and Transportation Safety and is a recipient of the Webb Prize from the UK Institution of Civil Engineers. He is a Fellow of the Chartered Institute of Transport and a Senior Member of the Institution of Engineers, Singapore. He has also served as a consultant for international agencies, such as the UN-Habitat, Asian Development Bank and Cities Development Initiative for Asia.

Grazia Concilio holds a PhD from the University of Naples, she is associate professor in Urban Planning at DAStU. She carried out research activity at the RWTH in Aachen (D), and at IIASA in Laxenburg (A) and at the Concordia University of Montreal, Canada. Component of several research projects, responsible for a CNR national project aiming at developing an e-governance platform for the management of Natural Parks; she has been and is responsible for Politecnico di Milano of several European research projects; she is author of diverse international publications.

Antonio Corradi graduated from University of Bologna, Italy, and received MS in electrical engineering from Cornell University, USA. He is a full professor of computer engineering at the University of Bologna. His research interests include distributed and parallel systems and solutions, middleware for pervasive and heterogeneous computing, infrastructure support for context-aware multimodal services, network management, mobile agent platforms. He is member of IEEE, ACM, and Italian Association for Computing (AICA).

Mark Deakin is Professor of Built Environment and Head of the Centre for Sustainable Communities in the Institute for Sustainable Construction at Edinburgh Napier University. His research is inter-disciplinary, cutting across academic, scientific and technical boundaries and works thematically to uncover what ICT-related actions contribute to smart and sustainable city development. This work has involved him developing ICT-related policies mapping out the social needs and informational requirements of urban sustainability and eGovernance challenges the digitisation of communication technologies pose for the development of energy-efficient-low carbon zones as smart city-districts.

Salvatore Di Dio was born in Palermo in 1983; his background is in architecture and engineering. He graduated at the Palermo University (Italy) in 2007 and he got a master in urban sustainability at the Free University of Bozen (Italy) in 2010. From 2011, as Ph.D. student at the University of Palermo, he carried on a research regarding new design tools to trigger urban and social innovation in marginal and disadvantage contexts. For his studies, with a "Istituto Superiore Mario Boella" (Turin, Italy) fellowship, in 2012 he was Ph.D. visiting student at the MIT Department of Urban Studies and Planning, (Cambridge, MA, USA). In these last years he also worked, as designer and project manager, for several Italian design firms. He's co-founder and Director of the research lab "PUSH - civic startup" and co-founder and Design Manager of the architecture and urban innovation studio "Inés Bajardi and partners".

Promiti Dutta received a B.S. in chemical engineering, a master's degree in public health in biostatistics and epidemiology, and an M.S. in electrical engineering from Columbia University. She is currently a Ph.D. candidate in engineering with a focus in electrical and environmental engineering at Columbia. Her research interests are in the application of networking, communication, and machine learning algorithms towards the integration of electric vehicles and other technologies in the smart grid. She has authored dozens of book chapters, journal articles, conference papers and technical reports. Prior to joining the Center for Computational Learning Systems, Promiti was the Assistant Dean for Innovation, Community Engagement, and Entrepreneurship at Columbia University's School of Engineering and Applied Science where she was the lead instructor for the first year core engineering design course and the founder for the university's first residential business incubator in the Ivy League for undergraduate students.

Micari Fabrizio was born in Palermo (Italy) 1963 he graduated in Mechanical Engineering at the University of Palermo with laude on July 1986. He is Full Professor of Manufacturing Technology, Department of Chemical, Management, Information and Mechanical Engineering, Polytechnic School, University of Palermo. He is President of the Board of the Deans of the Faculty of Engineering of the Italian Universities from 2013 and he is the delegate of the Rector of the University of Palermo to the management of EU research projects from 2009. The scientific activity resulted in more than 260 scientific papers, published on peer-reviewed international journals (more than 90) or on the proceedings of well qualified international conferences.

Primavera De Filippi is a researcher at the CERSA / CNRS / Université Paris II. She is currently a research fellow at the Berkman Center for Internet & Society at Harvard, where she is investigating the legal challenges of "governance-by-design" in online decentralized architectures, such as Bitcoin, Ethereum etc. In addition to her academic research, Primavera acts as a legal expert for Creative Commons in France, as a coordinator for the Open Knowledge Foundation, and as an administrator of the Communia association for the public domain.

Marco Fiore is a researcher at the Institute of Electronics, Computer and Telecommunication Engineering (IEIIT) of the National Research Council of Italy (CNR). Prior to that, he was a Maître de Conférences (tenured assistant professor) at INSA Lyon, France, a PostDoc fellow at Politecnico of Torino, Italy, and a visiting researcher at Rice University, TX, USA, and Universitat Politècnica de Catalunya, Spain. He received Master degrees from University of Illinois at Chicago, IL, USA, in 2003, and Politecnico di Torino, Italy, in 2004, as well as a PhD from the latter institution in 2008. He also holds an Habilitation à diriger des recherches (HDR) from INSA Lyon and Université Lyon I, France, obtained in 2014. He is an associate member of Inria, France, and a co-founder of the UrbaNet team within the same organisation. His research interests include user mobility characterisation in wireless access and spontaneous networks, mobile data mining and analysis, content download, upload and propagation in vehicular networks.

Luca Foschini graduated from University of Bologna, Italy, where he received PhD degree in computer science engineering in 2007. He is now an assistant professor of computer engineering at the University of Bologna. His interests include distributed systems and solutions for pervasive wireless computing environments, system and service management, context-aware services and adaptive multimedia, and management of Cloud computing systems. He is member of IEEE and ACM.

Gebrye Kefelew Gebremariam is a Project Coordinator in AFSR for Ethiopia Social Accountability Program Phase 2 (ESAP2), which is financed by the World Bank - Multi Donor Trust. He holds a Master's degree in Urban Development and Management from College of Development Studies, Addis Ababa University. His research interests are on issues related to sustainable development, project planning and management, urban development planning, housing, infrastructure and environment.

Silvia Giordano has been assistant researcher at the Politecnico di Torino for a number of years in the field of integrated assessment of efficient urban planning at Smart District level using decision support systems. She holds a European PhD in Technological Innovation for the Built Environment. Her research interests include: territorial and urban transformations, sustainability assessment methods at macro and micro scale, decision support systems.

Andrew Hudson-Smith is Reader in Digital Urban Systems at the Centre for Advanced Spatial Analysis (CASA) where he is Director. He is Editor-in-Chief of Future Internet Journal, a Fellow of the Royal Society of Arts and a member of the Greater London Authority Smart London Board. His research is focused on location-based digital technologies he has been at the forefront of web 2.0 technologies for communication, outreach and developing a unique contribution to knowledge. He is author of the Digital Urban Blog (www.digitalurban.org). He works on the Internet of Things, smart cities, big data, digital geography, urban planning and the built environment.

Stephan Hügel is a doctoral researcher at the Centre for Advanced Spatial Analysis (CASA). His research is focused on the "Smart Cities" movement, and the impact of open data and infrastructure on cities and the people who live in them. He holds an MA in Digital Humanities from UCL, and a BA in English Literature from Trinity College Dublin.

Raffaele Ianniello graduated from the University of Bologna, Italy, where he received a Master degree in computer engineering in 2013. He is now a research assistant at the same university. His interests include distributed systems, spatial analysis, semantic web, and mobile sensing.

Andreas Koch studied Architecture at the Technical University in Berlin and City Design and Social Science at the London School of Economics and holds a Master degree in Energy Management. As chartered Architect and registered Energy Consultant (dena) he has worked in the field of energy efficient construction for Minergie buildings and Passive Houses in Switzerland and Germany. In 2007 he joined the European Institute for Energy Research (EIFER) working on energy efficiency in buildings and urban neighbourhoods. Since 2012 he is leading the research group "Energy Planning and Geosimulation" at EIFER. Mr Koch is a certified auditor for the German sustainability assessment system for new districts (DGNB-NSQ), he regularly contributes to teaching programmes as the KIC InnoEnergy Generic Master Programme "Energy Technologies" – ENTECH, the HECTOR School of Engineering and management, Engineering Module, both at KIT, DGNB training for new DGNB neighbouhood auditors, as well as the Mastère Spécialisé Immobilier Bâtiment Énergie at the École des Ponts ParisTech.

Sekhar Kondepudi has 25 years of global business, product and academic experience in a variety of technology verticals including Smart Cities, Internet of Things and Energy Efficiency in the Built Environment. He is a Vice-Chair for the Focus Group on Smart Sustainable Cities at the International Telecommunications Union (ITU) developing global standards. Active in providing strategic advisory services related to Smart Sustainable Cities, Internet of Things (IoT) and Energy Efficiency, he is currently an Associate Professor of Smart Buildings and Smart Cities at the National University of Singapore. He has made many presentations in global forums on the topic of smart sustainable cities and building energy efficiency including Singapore, Bangkok, Pusan, Colombo, Turin, Madrid, Riyadh and Qatar. He has over 40 technical publications to his credit and has conducted multiple trainings and workshops globally. In the past, Dr. Kondepudi has led Global Product Management and Business Development for Smart+ Connected Communities (S+CC) Platform & Solutions at Cisco Systems. He headed up a team developing software, related products and solutions for Smart Buildings and Smart Cities with successful implementations in multiple global locations including Songdo, Korea. Previously, Prof. Kondepudi has been General Manager of Mobile Devices for Wind River Systems, Director of Business Development at Motorola, with the electric utilities industry at the Electric Power Research Institute (EPRI) in Palo Alto, California and the United States Environmental Protection Agency (US EPA).

Ramita Kondepudi is currently a student of engineering and computer science at Harvey Mudd College, Claremont, California. Her interests lie in being able to apply software and engineering technologies to improve sustainability in urban and rural environments. She has been very pro-active with sustainability having set up a biogas plant in Bangalore, written a quick start guide for green schools, tackled urban environmental issues in the Global Issues Network (GIN), 350.org and has a blog http://thinkgreenspeak.blogspot.com. Ramita has won numerous awards including a scholarship from the Society of Women Engineers, highest in school for her IGCSE (Cambridge) exams, 1st place (Gold) in the 2010 All India Robotics Olympiad, the 2012 All India National Sparrow Environment Award and a Young Researcher Award at 2012 National Conference on Healthcare Management for her paper on "Environmental Considerations for Hospitals". She has a Black Belt in Tae Kwon Do, speaks fluent French and has over 10 years of training as a vocalist in Carnatic (South Indian Classical) music.

Eugenio Leanza is the Head of Division JESSICA and Investment Funds (EIB) since 2007. JESSICA stands for Joint European Support for Sustainable Investment in City Areas. This initiative is being developed by the European Commission and the European Investment Bank (EIB), in collaboration with the Council of Europe Development Bank (CEB). Before joining JESSICA, Eugenio Leanza was Head of Division in the Directorate for Lending Operations in Europe (Italy, Malta and Cyprus Department) and Deputy Head of EIB Banking Sector in the Credit Risk Department. Between 1987 and 1991, he was a specialist in corporate lending, convertible warrants/bonds operations, and industrial groups restructuring at Mediobanca, Milan. He holds an Honours Degree in Economics from Bocconi University in Milan and is a Chartered Accountant.

Tebarek Lika is an assistant professor of Development Geography at Addis Ababa University, Ethiopia. Tebarek completed a PhD in Development Geography at Bayreuth University (BIGSAS) and holds a Master's in Human Geography from Addis Ababa University and a Master's in Critical Practitioner Inquiry for Educators from Umea University, Sweden. He has served in various administrative positions as Graduate Program Coordinator to Head of the Department. He has publications on housing, urban development, value chain governance and inter-firm relationships, ethnic entrepreneurship, gender, the informal sector, migration, urban and rural livelihoods and climate change issues in Ethiopia and few of his papers are published and widely referred to in Ethiopia and abroad. His research interests are in the areas of urban economic development, value chains, ethnic entrepreneurship, gender, housing, climate change, infrastructure and development, urban and regional planning.

Wolfgang Loibl holds Master and PhD degrees in Geography and Spatial Planning and a MSc degree in Organization Development. He was working for several years as urban and regional planner and since more than 25 years at AIT - Austrian Institute of Technology as regional scientist, spatial planner and spatial modeler focusing on urban development issues, urban energy issues and on climate adaptation topics. He was teaching as university lecturer during a decade “GIS-based spatial modeling” at Vienna University and recently “Applied Systems modeling” at Graz University, Austria. At the AIT he holds the positions Senior Scientist and Thematic Coordinator for the research field Sustainable Cities and Deputy Head of the Business Unit “Sustainable Buildings and Cities”.

Patrizia Lombardi (PhD, MSc, BA/MA) is Full Professor of Urban Planning Evaluation and Project Appraisal and Head of the Interuniversity Department of Regional and Urban Studies and Planning of Politecnico and Università di Torino. She is Scientific Coordinator of the S3+ Lab - Urban Sustainability & Security Laboratory for Social challenges, at Politecnico di Torino and Scientific Director of the UNESCO Master “World Heritage and Cultural Projects for Development” managed by ITC-ILO (since 2010) (worldheritage.itcilo.org). She is an established figure in the field of evaluating sustainable development for over 20 years, publishing widely in the subject area and coordinating, or serving as lead partner, in a number of Pan-European Projects, including BEQUEST, INTELCITY, INTELCITIES, ISAAC, SURPRISE, PERFECTION, MILESECURE-2050, DIMMER, POCACITO. She is representative member of the EIT-ICT Lab of Trento Rise and chair of several International Scientific Committees on Smart Cities, e-governance and cultural heritage. She has received an award in 2012 by the Alumni of Salford University of the Great Manchester for her carrier achievements.

Elena Masala holds a PhD in Architecture, in 2003 she starts working as Research Fellow at Politecnico di Torino (Italy). Since 2010, she carries out her activity at SiTI - Higher Institute on Territorial Systems for Innovation, in the research field of geovisualization. Her experience ranges from 3D modeling to video animations, from Geographic Information Systems (GIS) to interactive visualisations, with a strong experience on virtual environments. Her work aims at supporting spatial planning and decision-making processes by means of visual analysis, data exploration and communication. Her activity focuses on the usability of Planning and spatial Decision Support Systems (PSS and sDSS) to be applied in the operational research. She is author of several publications on both national and international books and journals.

Francesca Romana Medda is a Professor in Applied Economics and Finance at the University College London (UCL). She has been the Director of the UCL QASER (Quantitative and Applied Spatial Economics Research) Laboratory since 2010. Since 2012, she has served as an economic adviser to the UK Ministry of Environment and Agriculture (Defra) and in 2014 at the Ministry of Finance (Her Majesty’s Treasury). Her research focuses on project finance, financial engineering, and risk evaluation in different infrastructure sectors such as: the maritime industry, energy innovation and new technologies, urban investments (smart cities), supply chain provision and optimisation, and airport efficiency. She works actively with the private and public sector, such as for the European Investment Bank, the World Bank, UNESCO, UN-Habitat, WILLIS Re, HALCROW, and UITP. At present she holds several grants, and is co-investigator in the £6.2m EPSRC Programme Grant “Liveable Cities” and the £5.8m grant “New Business for Infrastructure Investments”. She has served on the Executive Board of Directors of a major public transport company in Italy since 2007.

Giulia Melis is an Architect, Master of Science degree in History and Conservation of Architectural Heritage. Since 2007 she holds a position as researcher at Urban Planning and Land Use management Unit at SiTI. She is involved on several projects on strategic planning and urban redevelopment, focusing on town planning aspects, assessment and definition of urban development scenarios through spatial support decision systems, relationship between urban-periurban areas, impacts of urban policies on citizens' health. Furthermore, she gained relevant international experience thanks to the involvement in several European funded projects and networks aiming at implementing innovative solutions for reclaiming degraded urban and industrial areas, analyzing the relationship between planning and transport in order to develop accessibility instruments to be used in planning processes. She has also been collaborating in didactic courses at Politecnico di Torino, as assistant and lecturer in courses of Geography and Urban requalification.

Francesco Molinari is currently research associate on Frugal Government at Politecnico di Milano and visiting professor on innovation and entrepreneurship at the Ulster Business School of the University of Belfast. As research and project manager he has worked for several public and private organizations in Europe, including clients from Belgium, Cyprus, Greece, Israel, Italy, Portugal, Slovenia and the UK. For the European Commission, among others, he wrote in 2008 a study for the assessment of the Living Labs approach in the EU innovation and Future Internet scenario. He has done consultancy to several Italian Regions and central government bodies in topics related to the establishment and management of Living Labs and to innovation policy renewal.

Elsa Negre received her Ph.D. in Computer Sciences in 2009 from Université François-Rabelais de Tours, France. She was a postdoctoral fellow at Université du Québec en Outaouais (UQO), Canada in 2010-2011, then at Laboratoire d'Informatique Nantes-Atlantique (LINA), France in 2011. She is currently an Assistant Professor at Université Paris-Dauphine, France. Her research interests include recommender systems, similarity measures, information systems and knowledge management, data warehousing and social network analysis, early warning systems and smart cities. Dr. Negre authored and co-authored more than 20 publications in refereed journals and conferences.

Peter Palensky is Professor for intelligent electric power grids at TU Delft (Netherlands). Earlier he was Principal Scientist at the AIT - Austrian Institute of Technology, CTO of Envidatec Corp., Hamburg, Germany, associate Professor at the University of Pretoria, South Africa, Department of Electrical, Electronic and Computer Engineering, University Assistant at the Vienna University of Technology, Austria, and researcher at the Lawrence Berkeley National Laboratory, California. He is active in international committees like ISO, IEEE and CEN. He carries a PhD (EE, 2001) from the Vienna University of Technology and is an IEEE senior member. His research field is complex energy systems and smart grids.

Candace Partridge is an engineering doctoral student working under the supervision of Prof Francesca Medda in the QASER Laboratory at University College London. Her research focuses on developing a practical approach to produce integrated plans enabling cities to manage and invest in their infrastructure more effectively in order to achieve long-term impacts in energy security and climate action. She explores how such investment strategies can best be structured, including how associated risks can be characterised, in order to attract funding from investors. She comes from a multidisciplinary background and has an MSc in Astrophysics, also from UCL.

Hervé Rivano is an INRIA researcher (Chargé de Recherche). He is the head of the UrbaNet team which focuses on wireless networks for digital cities. He is « Habilité à Diriger les Recherches » since june 2014. Prior to that, he has been hired as a CNRS researcher in october 2004 and as an Inria researcher since january 2011. He obtained his PhD in november 2003 from the University of Nice-Sophia Antipolis. He was supervised by Afonso Ferreira (CNRS) and Jérôme Galtier (Orange Labs). He graduated from the Ecole Normale Supérieure de Lyon. His research interests include combinatorial optimization and approximation algorithms applied to network design and provisioning. He focuses on capacity/energy tradeoff for urban cellular and mesh networks design. He also focuses on multicommodity flow algorithms, graph coloring in telecommunication network settings, and Shared Risk Groups fault tolerant networks.

Gianfranco Rizzo is a Full Professor of Environmental Technical Physics at the Polytechnic School of the University of Palermo. During his academic career he had a research experience with the International Energy Agency and the University of California and he is referee of the National Research Council of Italy and of the Italian Ministry of University and Research. He is associate Editor of Journal of Ecology and The Natural Environment and a member of the editorial board of International Journal of Sustainable Development and Planning. He is author of about 300 scientific publications and co-author of three books on the issues of energy efficiency of buildings.

Camille Rosenthal-Sabroux is full Professor at Paris-Dauphine University. She is a graduate of PHD Pierre et Marie Curie, Paris VI, (1971) and HDR (habilitation à diriger des recherches) in Computer science (1996). From 1976 to 1989, she was assistant professor in Paris XI, in Expert System. Since 1989, she is Professor at Paris-Dauphine University and advises some large companies (AG2R, Sallustro Redel Management, Bureau Veristas, PSA Citroën, Arcelor, France Télécom) about Information Systems, Knowledge Mangement, Decision Science. She is the founder of the SIGECAD Group, which domain topics are Information System, Knowledge Management and Decision Aid. Her main research topics are: Modeling Language (UML), Decision Aid, Knowledge Acquisition, Knowledge Management, and Information System. She is the Director of the Master "Extended Company's Information System: Audit and Consulting". She published several books and articles.

Maurizio Rossi received the B.Sc degree in Computer Science and Industrial Automation Engineering from the Universitá Politecnica delle Marche and the M.Sc. degree in Telecommunication Engineering from the University of Trento in 2008 and 2012 respectively. He is currently a PhD degree candidate at the Information and Communication Technology International Doctoral School at University of Trento. His research activity is in the field of energy aware hardware-software codesign of embedded electronic systems for the IoE and the Smart Grid. His research interests include the design of energy neutral wireless sensor networks for environmental monitoring, renewable and green energy harvesting, storage and management, time series analysis and forecasting for renewable energy sources integration in the Smart Grid.

Flora Roumpani is a doctoral researcher at the Centre for Advanced Spatial Analysis and holds a diploma in Architecture and Engineering from the Department of Architecture in the University of Patras, and an MRes from UCL. During her studies, she worked as a researcher in the Laboratory of Urban and Regional Planning in research projects relating to urban analysis and visualization. For 4 years, she worked as an architect as part of the urban planning team in Doxiadis Associates in several projects in Greece and abroad. Her research interests include issues concerning the future of the city, virtual environments and urban modelling and these are reflected on her blog (http://en-topia.blogspot.co.uk/).

Ralf-Roman Schmidt finished his studies in process engineering at the University of Bremen (Germany) in 2005 where he received his PhD-degree in 2013. From 2005 to 2009 he worked at the IWT Bremen (Foundation Institute of Materials Science) in the field of thermo-fluid dynamics. Since June 2009, he is working at the AIT - Austrian Institute of Technology. Starting on the analyses of thermal power plants, he became soon responsible for the development and management of national and international research project in the field of district heating and cooling networks and smart cities. His research priorities are strategic planning, integrated design and optimized operation of smart thermal networks. In 2011, the Joint Programme on Smart City of the European Energy Research Alliance (EERA) was formed, were Ralf-Roman Schmidt became Deputy-Coordinator of the sub-programme on Urban Energy Networks. Additionally, he is vice chairperson of the European District Heating and Cooling plus (DHC+) Technology Platform.

Catalina Spataru (PhD) is a Senior Researcher in Smart Grids and Energy Networks at UCL Energy Institute, London, UK. Her expertise is on energy systems, networks and security. She has been involved in projects funded by EPSRC, EC, British Council, industry and led projects on power blackouts, energy networks, Ukraine-Russia-EU energy future. She is supervising PhD students, teaching smart energy systems for MSc students at UCL, acted as scientific committee chair for conferences, delivering several invited talks at international events, participating in public engagement activities. She had a Socrates—Erasmus scholarship at Complutense de Madrid in 2002 and it has been a visiting researcher at MIT, USA working on vulnerability of interdependent energy networks (gas and electricity) in May 2014.

Razvan Stanica is an associate professor in the Telecommunications department at INSA Lyon, and a researcher within the INRIA UrbaNet team at the CITI laboratory. He obtained a M.Sc. in Computer Networks from the University of Toulouse and a M.Eng. in Electrical Engineering from the Polytechnic University of Bucharest, both in 2008. In November 2011, he received his Ph.D. in Computer Science from the National Polytechnic Institute of Toulouse (INPT) for his work on congestion control in vehicular ad-hoc networks. His research interests focus on wireless networking solutions in dynamic environments, with a special interest in applications related to mobility and intelligent transportation.

Matteo Tabasso holds a Master of Science degree in Architecture and Urban Planning of Politecnico di Torino (Italy). Since 1999 he developed an extended experience in transport and town planning both working for public authorities and for research institutions. Since July 2006 he has been working at SiTI as project manager, coordinating researches and projects in strategic and urban planning and development. The main focus of his recent experience concerns the link between urban environment and health and the relationship between transport and urban planning. He developed an extended international experience thanks to the participation in several European networks and projects on urban issues.

Luca Tamburini received the Bachelor's degree in Telecommunication Engineering in 2011 and a Master's degree in Mechatronic Engineering in 2014 from University of Trento. He has been a researcher fellow at the Department of Industrial Engineering of University of Trento, working on energy efficiency and scheduling algorithms. He also collaborated within the EU FP7 project GreenDataNet, aimed at the development of a smart energy management system to improve energy and environmental performance of datacenters. He is co-author of several articles on Smart Grids, Home Automation, Hybrid energy storage systems and forecasting algorithms. Along with this, his research interest are on green technologies, robotics and control theory.

Fabrice Valois is full professor in the Telecommunications Department of INSA Lyon (France), since 2008. He is also the head of the CITI-Inria laboratory which is focused on smart and wireless communicating objects. In January 2000, he obtained a Ph.D. in computer science about Performance Evaluation of Hierarchical Cellular Networks from University of Versailles (France). His research interests cover networking issues for wireless sensor networks, and generally speaking for wireless multihop networks. More particularly, his research works are focused on self-organization, routing and data aggregation, from theory to practise. He was invited professor in Ecole Polytechnique (Montréal, Canada) in 2007 and visiting professor in Northwestern Polytechnical University of Xi'an (China). He is invited professor in the university of Shanghai JiaoTong University in 2011.

Ignazio Vinci is an Architect with Ph.D. in Urban and Regional Planning; he's Assistant professor of Urban planning at the Palermo University, Polytechnic School. In 2014 he was also visiting professor at the School of Geography, Planning and Environmental Policy of the University College of Dublin with a cycle of lectures on the Italian planning system. He carries out researches at the Department of Architecture on a range of themes including the analysis of urban phenomena in Europe, regional planning and local development processes, urban-rural relationship, innovation in spatial planning and territorial policy. He has been a consultant for national, regional and local authorities in the design, implementation and evaluation of plans for urban regeneration and territorial development. On these topics and experiences he has published more then a hundred of works including volumes, book chapters and articles on scientific journals. His last book is "The spatial strategies of Italian regions", Milan, 2014.

Yueying Wang received a Bachelor degree in Civil Engineering from Dalian University of Technology, China, and a PhD degree in Transportation Engineering from the National University of Singapore. She has more than six years of research experience in transportation and safety, and has published several academic papers on maritime safety and road safety. Besides, she has been involved in transport related consultancy such as road safety audits, transportation master plan reviews and traffic impact analyses.

Leon Wu is an entrepreneur and computer & data scientist in software engineering, machine learning, data mining, optimization, security & reliability, cyber-physical systems, smart power grids, smart buildings, smart oil & gas, energy informatics, financial analytics, and system development and integration for complex, large-scale, real-time data analytics applications using Human Machine Interface visualization. With years of work experience in academia, technology and financial industry, he is an inventor of over seven granted and pending U.S. patents and author of dozens of book chapters, journal articles, conference papers and technical reports. Bloomberg, BusinessWeek, National Science Foundation, and IEEE Computer Society have featured his work. Leon received his graduate degrees in Computer Science from Columbia University and bachelor's degree in physics from Sun Yat-sen University. He is living in New York City and enjoys running in Central Park.

Gerhard Zucker is a senior researcher at AIT - Austrian Institute of Technology in the field of sustainable building technology. His research area includes building automation and controls for optimization of energy efficiency and he works on methods to recognize and evaluate behavior of persons for optimizing building usage and maximizing comfort. He finished his Dr. techn. (PhD) at Vienna University of Technology in 2006. In the following he worked on different projects in the field of building automation and artificial intelligence. His publication record includes editorship of two books and numerous scientific publications. He is associate editor of the IEEE Transactions on Industrial Informatics and is continuously active as session chair and track chair in various conferences.

Index

T

U

V

W