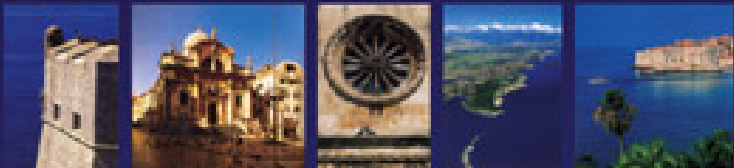
SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS

Volume III



Naim H. Afgan
Željko Bogdan
Neven Duić
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editors

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Volume III

Proceedings of the 3rd Dubrovnik Conference
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editors

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FOREWORD

Sustainability is a new discourse aimed at promoting a new strategy in the development of energy, water and environmental (EWE) systems. It is becoming increasingly clear that the quest for sustainable development requires integrating economic, social, cultural, political, and ecological factors. It requires grassroots initiatives, as well as simultaneous consideration of the local and global dimensions, and of the ways by which they interact. It also requires broadening of the space and time horizons to accommodate the need for intra-generational as well as international equity. The behavior and properties of a EWE system arise not merely from the properties of its component elements, but to a large degree also from the nature and intensity of their dynamic interlinkages. It has become evident that the complexity of these problems requires enhancement and deepening of the understanding of the implications of the different aspects of sustainability. Resources, economy and environment are the key components that affect the quality of life on our planet. It has also been recognized that the social aspect, including information exchange, is of fundamental importance in understanding sustainable development. In this respect the 3rd Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems held in 2005 have offered the best opportunity for the dissemination, exchange and promotion of new ideas for interdisciplinary, multi-cultural and multi-criteria evaluation of EWE systems.

Consequently, the main objectives of the conference were:

- Development of new methods for the analysis and evaluation of EWE systems (such as emergy and exergy analysis, life cycle assessment, ecological footprint, MIPS, etc.).
- Analysis of potential scientific and technological processes addressing the interactions between energy, water and environment.
- Promotion of a new field of sustainability science that seeks to understand the fundamental character of interactions between EWE systems and society.
- Development of inter-disciplinary partnerships bringing together leading experts in physical, life, and environmental sciences, engineering, economics, and social sciences and informatics.
- Development of models of energy, water, and environmental systems, and their evaluation.
- Enhancement of methodologies for assessing the comparative sustainability of different EWE systems options, taking into account economics, environmental resource use, and social validation.

Among the number of the presented papers those which have met the standard of the reviewing procedure adapted for this volume are selected.

The Proceedings comprises of the following chapters:

- Sustainability Science.
- Energy Policy and Planning.
- New Renewable Energy Sources and Energy Efficiency.
- Energy Cogeneration.
- Water Management.
- Water Desalination and Treatment.
- Environment Assessment and Evaluation.
- Environment Managment.

The leading articles in each chapter are contributions from important authors in field.

It has to be recognized that without support of UNESCO this volume will not be available. In this respect the editors of the Proceedings of the Third Dubrovnik Conference on the Sustainability Development of Energy, Environment and Water Systems are very pleased to express our admiration to the His Excellency Mr. Koichira Matsuura, the Director General of UNESCO for his effort in supporting sustainable development on our planet.

The support of European Commission INCO programme, of Hrvatska elektroprivreda d.d. – Zagreb and of Ministry of Science, Education and Sports of the Republic of Croatia is acknowledged.

The editors of this volume would like to express high appreciation to the Members of the Scientific Advisory Board of the Conference in promotion of the Conference.

It is the great pleasure of editors to recognize active role of the Members of International Scientific Committee in promotion and reviewing papers. The authors of the papers deserve high appreciation for their cooperation in the preparation of the manuscript of this volume. It is our obligation to recognize great contribution of the Organizing Committee.

Editors:

Naim H. Afgan, Željko Bogdan, Neven Duić, Zvonimir Guzović

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SUSTAINABILITY SCIENCE

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SUSTAINABILITY AND SAFETY EVALUATION OF ENERGY SYSTEM

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In the assessment of long term behavior of the complex system we have to introduce notion of sustainability as the measure for the quality of the system. It is defined as the quality which is measuring the ability of our society to secure and not compromise the ability of future generation to have quality of the life at least the same as our generation. The safety property of complex system is immanent to any system. It reflects quantitative merit for degradation of the system. Also, it includes rate of changes for any process leading to degradation of the system. Environmental degradation is among the most pressing global issues confronting modern society. Sustainability and safety are linked with the similar essential idea to prevent degradation of the quality of the system. The sustainability is defined as the aggregation function of physical, social, technological, environmental and resources parameters. The safety is time derivative of the sustainability index. Demonstration examples of application of the multi-criteria in evaluation Sustainability Index and Safety Index of the system proves that the evaluation of complex system is involved in sustainable development research with associate uncertainty suggesting that the research should move toward the search for general principle and guiding questions for new investigation.

1 Introduction

The vulnerability of modern world is an important issue to our humanity. For this reason it is of great importance to understand the state of system which may lead to the hazardous degeneration of any life support systems [1]. We now live in the world with treats that most of our sophisticated man made systems may become source of the hazardous species which may effect human lives. Fundamental safety consciousness is a challenge for understanding the need for the development of appropriate methodology for the assessment and evaluation of potential standard for safety. We are witnessing everyday that the safety notion is a key issue in human life. It has effects with individual and collective consequences in long term and short term span of time.

The development of sustainability science has become ultimate goal of modern society [2]. Like any other knowledge the safety science is cumulative resource of human history. Number of hazardous events is increasing which may be justified as consequence of the need for the better understanding individual events as much as the notion of collective properties of life support systems. It is immanent to any life support system to be described with the respective properties representing collective set of individual indicators. Relation between the safety properties of complex system and any other property of complex system is the fundamental quality indicator of the system.

In the assessment of long term behavior of the system we have to introduce notion of the sustainability as the measure for the quality of the system [3,4]. It is defined as the quality which is measuring the ability of our society to secure and not compromise the ability of future generation to have quality of the life at least the same as our generation. This measurement is aimed to facilitate control of the steady state of our systems. The safety of any system is closely linked to the change of quality of the system. It is known in thermodynamics that any change of the entropy of the system is directed to its maximum. If we look at the global scale of complex systems the maximum entropy will mean the death of the system. If we consider complex system defined with sustainability as the indicator of its quality, it is logical to assume that the time change of sustainability of the system may be used as the measure for the potential changes of safety of the system. Even it was accepted that present science is not in position to allow us to explain or model the complex system in the world, in the past number of years the attention was focused to study phenomena that seemed to be governing the spontaneous appearance of novel structure and their adoption to the changing environment [5]. Most of the life support systems are convoluting to the formation of the new structure and require a new approach in the evaluation of the system. The complexity of the systems is increasing in current decade. There are many reasons. Among those are: ontological changes, epistemological changes and changes in the nature of decision making. Sustainability development requires integrating economic, social, cultural, political and ecological factors. From the scientific viewpoint there are two basic tasks: one of the most important is the identification and understanding the linkages between different factors and different scales that originate the possible changes in one component of the system into other parts of the system. Other task is understanding the dynamic of the system.

Environmental degradation [6] is among the most pressing global issues confronting modern society. Investigation of the potential capacity of the complex system to cause environmental degradation is an important goal of modern science. Study of these problems has imposed the demand for the assessment of safety properties of complex system [7]. In this respect definition of the safety property of the system is the essential parameter which define the adaptability of the system to its surrounding. Since sustainability of the complex system is by itself its property of the system, it is acceptable to take the sustainability change as the property indicator for the safety of the system.

Sustainability and safety are linked with the similar essential idea to prevent degradation of the quality of the system. As sustainability is defined as the aggregation function of the physical, social, technological, environmental and resources parameters it can be defined that the safety is time derivative of the sustainability indicators. Abrupt change of the sustainability will lead to the disastrous degradation of the system. Similarly, it can be taken that any adverse change in the sustainability indicator as the respective measure for the safety degradation of the system.

2 Sustainability

Sustainability comprise complex system approach in the evaluation of the system state. By its definition sustainability include definition of quality merits without compromising among different aspect of system complexity. It is of paramount importance for any system as the complex system to quantify elements of complexity taking into a consideration various degree of complexity. As regards complexity elements of the system it can be codified as the specific structure reflecting different characteristics of the system as shown in Figure 1.

Any process is characterized by the entropy production as the measure of the irreversibility of the processes within the system. So, the complexity element of the system is reflecting internal parameter interaction can be defined by the entropy production in the system. In the complexity definition of system one of the element is entropy generation on the system or exergy losses in process [8].

Complexity elements of the economic indicators are structured in different levels are intrinsic to the specific levels and are measured in different scale. In the classical evaluation of system the economic merits are of primary interest. Since the economic quality is reflecting optimization function imposing minimum finale product cost, there are a number of parameters which are of interest to be taken into a consideration in the mathematical model for the determination of the optimized values of required for its evaluation.

Mutual interaction between the system and its surrounding is immanent for any life support system. As it is known the system is taking material resources from the surrounding and disposing residual to the environment. Among those residuals are the most important those which are in gaseous form and are dissipated to the environment. Also, most of the energy system is disposing low entropy heat to the environment.

The social element of complexity of the system is property of the complex system. In the social aspect of the system is included risk of environmental changes, health and nuclear hazards and may have to deal with a compounding of complexity at different level. Also, under social constrain reflecting social aspect of complexity of energy system are added values which improve the quality of the human life.

The technology quality of the system is the element of the complexity of the system. It may be defined and qualified as the potential upgrading of the individual part of the system and also as the interrelation among the elements. In the language of complex system this property can be understood as the inherent creativity of spontaneous appearance of novel structure. Thermodynamically, information introduced in the system is the negentropy as the result of the change in the structure of system leading to the better performance.

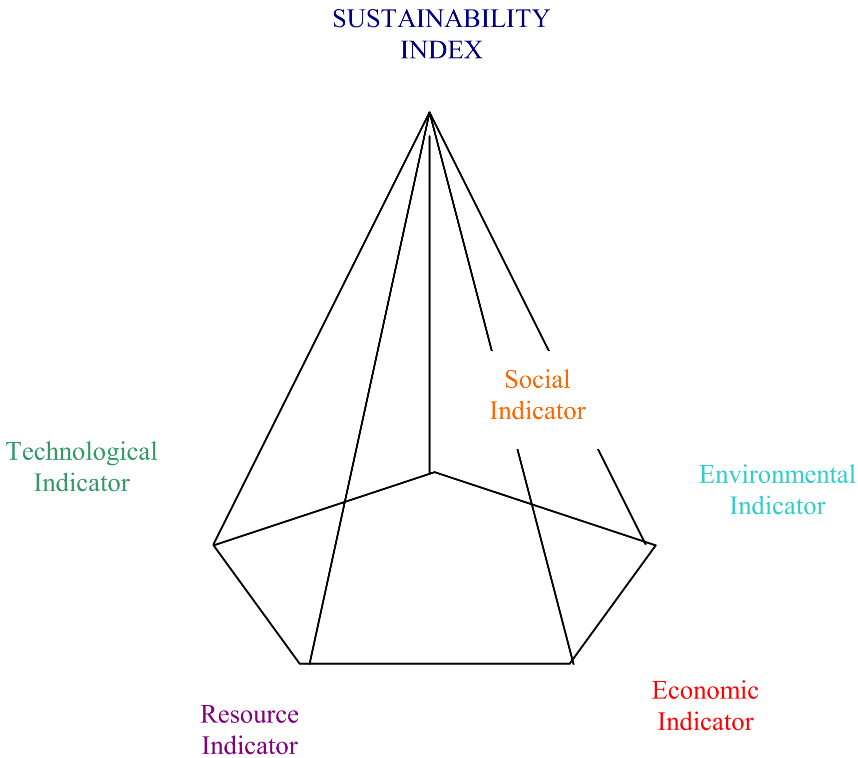

Figure 1. Sustainability Index Structure.

3 Safety

In the decade from 1991-2000, natural disasters killed a reported 665,598 people, probably an underestimate. And every year over 211,000 people are affected by natural disasters - two-thirds of them from floods. The number of weather-related disasters (droughts, floods and storms, for example) has doubled since 1996 while the number of geophysical disasters (e.g. earthquakes and volcanic eruptions) has remained steady over the last decade. And while floods cause the most damage, earthquakes run a close second, causing nearly US$270 billion of damage in the decade from 1991-2000.

The risk of natural disasters is often known and some preventive measures can be taken to protect human life, using selected materials and practices for building, avoiding flood-prone areas, etc. But it is often impossible to protect historic monuments from damage. Local authorities might also draw up a disaster action plan that could include briefing emergency services on how to limit the damage.

The safety of complex system property is immanent to any system. It reflects quantitative merit for the degradation of the system. Also, it includes rate of changes for any process leading to degradation of the system. It may be seen as the potential property predicting total degradation of the system. It is commonly known that any degradation of the system precede the changes of the main properties of the system. Since sustainability is a complex property of any system the description of the sustainability change in time scale will lead to the possibility to define those rates of changes which may have different consequences. There are different disasters which are reflection of the specific causes. For life support systems they are classified depending type of disasters. Figure 2 shows participation of the type of disaster in the total number of disasters [9].

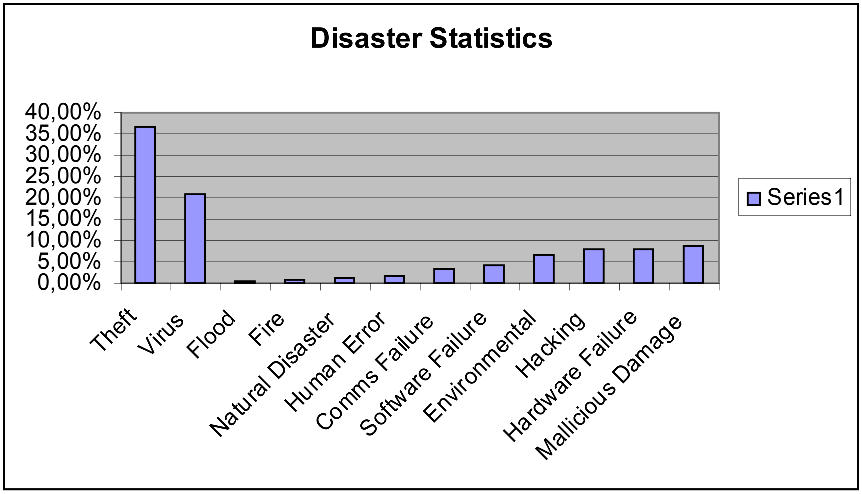

Figure 2. Disaster Statistics.

Taking into a consideration the change of individual elements of complexity we can design quantities which are of importance for definition of the potential states leading to the degradation of the system. In this respect we can analyze all elements of the complexity of the system and their change in the time scale.

Any process in the system is characterized with the entropy production as the measure of the irreversibility of the processes within the system. The stationary state of the process is characterized by the constant entropy production [15]. Non linearity of any process leads to the very fast degradation of the system. Typical example of this type of process is explosion. So, the rate of changes of entropy production in the system can be taken as the characteristic quality of the system which describes safety of the system.

The change of economic elements of indicator is intrinsic to the specific characteristic to be measured in the time scale. The time change of the economic indicators is common to the classical evaluation of system. Any crises of the economic system is preceded by corresponding changes in the economic indicator of the system. Qualitative measurement of these indicator changes may lead to the forecast of the economic crises which is only one element of the potential disastrous changes of the system effecting its safety. Figure 3 shows schematic presentation of Safety Index.

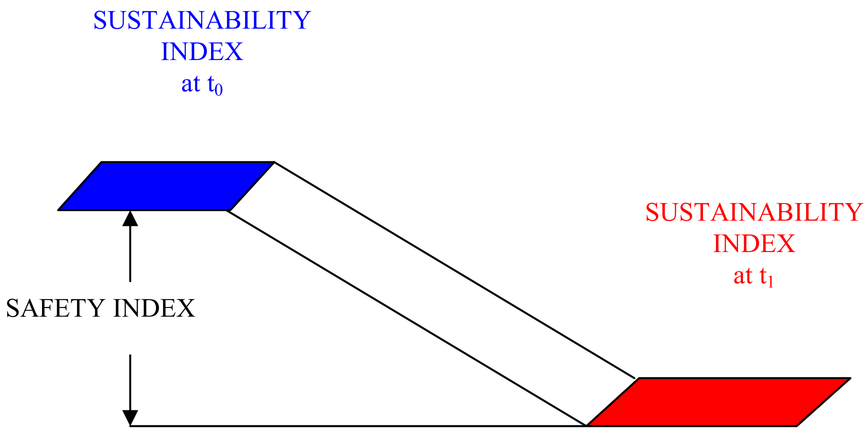

Figure 3. Schematic presentation of Safety Index.

The mutual interaction between the system and its surrounding is immanent for any system. The changes in the interaction rate will effect the safety of the system. If this processes are in steady state it can be considered that the system safe. As good example for this type of changes of indicators is the interaction of the system and its surrounding in the case of radioactive leaks from the nuclear facilities, which may lead to the hazardous consequences.

The change of social element of complexity of the system is property of the complex system. The social aspect of the system includes the risk of environmental changes, health and nuclear hazards and may have to deal with a compounding of complexity at different level. It is of interest to notice that some of the social changes are an inherent characteristic of the system. As example we can take any strike which is result of the economic changes of the system. Similar example can be seen if there is sudden change in the environment which will lead to the social disturbance.

4 Multi-criteria Evaluation of Sustainability and Safety

The complex system requires special methodology for the evaluation. Since complexity of the system is closely related to the multi-dimensional space with different scale, the methodology has to bear multi-criteria procedure in evaluation of the complex system.

The method for multi-criteria evaluation and assessment of complex system has proved to be promising tool for the determination of quality of the system. Even it was shown that there are some deficiencies in the presented method, it is a new route in tracing future analysis of complex system.

Sustainability comprises complex system approach in the evaluation of the system state. By its definition, sustainability includes definition of quality merits [10, 11]. It is important for the assessment of any complex system to quantify elements of complexity taking into a consideration various degree of complexity. The complexity elements of the system can be codified as the specific structure reflecting different characteristics of the system [12, 13]. It should include description of the interaction of internal parameters of the system and the system interaction with the different aspect of socio-economic-environment of ecosystem. The adoption of system to its surrounding leads to the physical, social and environmental interaction between the system and its surrounding. If there are number of different systems to be compared taking into a consideration potential behavior of individual system in the same surrounding there must be potential option which will give quantified quality priority among the system under consideration.

In order to define quantities which are used as measuring parameters in evaluation of the systems a following definition of qualities are adapted [14].

4.1. *Resource Quality*

Complex system is composed of number of elements which are connected with the aim to perform specific function, The organization of the system elements is reflecting optimized structure of the system following specific pattern. The material conversion characterization is thermodynamically justified process with optimal internal parameters of the system. In this respect the quantification of thermodynamic quality of the system is reflecting number of parameters which are defining the design of the system. Otherwise, it can be stated that the complexity element of internal processes in the system can be defined as the quality of material conversion measured by the thermodynamic efficiency of the system or any other parameter including integral parameters of thermodynamic system [15]. The material conversion process is characterized by the entropy production as the measure of the irreversibility of the processes within the system. So, the complexity element of the system reflecting internal parameter change and can be defined by the entropy production in the system [16]. Lately it is becoming popular to make exergy analysis of the system as the tool for the quality assessment of the system as whole and also determine exergy losses in individual elements of the system [8]. In this case the complexity element is entropy generation on the system or exergy losses in conversion process.

4.2. *Economic Quality*

Any complex system evaluation has to include economic validation of the product and it has to be the basic building block of the assessment procedure [17]. Also, it is indispensable element of the complex system. The quality of complex system has to comprise the economic validation of the system as the element of complexity. The main characteristic of the economic quality of the system is defined by the parameters comprising individual sub-elements of complexity reflecting economics of the system product. It is usually accepted to determine the economic indicator as the reflection of those sub-elements of complexity which are in the different scale. For this reason formation of fuzzy set of indicators for the consideration of energy system options is not trivial and has to reflect different conception of the system. Complexity elements of the economic indicators are structured in different levels are intrinsic to the specific levels and are measured in different scale. Since the economic quality is reflecting the optimization function imposing minimum finale product cost, there is a number of parameters which are of interest to be taken into a consideration in the mathematical model for the determination of the optimized values required for its evaluation [18].

4.3. *Environment Quality*

Mutual interaction between the complex system and its surrounding is immanent for any life support system [19]. For the complex system there are number of interaction which are defined by the respective parameters. On the first place, these interactions are the effects of system on the environment. As it is known that every system is taking material resources from the surrounding and disposing residual to the environment. Among those residuals are the most important those which are in gaseous form and are dissipated to the environment. Also, most of the complex systems are disposing low entropy heat to the environment. So the interaction between the system and environment is defined by the amount of material and energy transferred. The assessment of these interactions between the system and environment leads to recognition of the new element of complexity of the system. The basic components of environmental complexity element will be used in the assessment of the quality of individual system among the number of options under consideration. Every complex system is entity with the strong interaction with environment. There are ontological changes i.e. human-induced changes in the nature proceeding at unprecedented rate and scale and resulting in grooving connectedness and inter dependency. Molecules of carbon dioxide produced in the energy system leads to the global climate changes and adding new element to the complexity of energy system.

4.4. *Technological Quality*

The complex system structure organization is subject to the constant development in order to improve its functionality and performance quality [20]. The adoption of the system to the new requirement is complementary to the organization changes as the property of the complex system. The assessment of technological development implies adaptability of complex system to its evaluation. Information technology has demonstrated that its application to any system can lead to the intelligent system with self controlling ability. The potentiality for further improvement can be seen as the potentiality for self-organization of the system. This can be achieved with the use of information knowledge, organization and also introduction of new processes. It may be defined and qualified as the potential of the individual part of the system and also as the interrelation among the elements. In the language of complex system this property can be understood as the inherent creativity of spontaneous appearance of novel structure.. Thermodynamically, information introduced in the system is the negentropy as the result of the change in the structure of system leading to the better performance [22].

4.5. *Social Quality*

Social aspect of the complex system is important factor to define the quality of the system. Beside the adverse effect of the system on the environment, there may be another driving force for the social changes in the region [21]. It can bring new jobs, new investment, new infrastructure and many other advantages in the region. This quality of the system must be defined as the elements of the complexity of the system. The interactions of the system with society are properties of the whole, arising from the interactions relationship among the system and surrounding. With a number of options under consideration the social element of complexity of the system will comprise integral parameters and their evaluation. The social aspect of the system includes risk of environmental changes, health and nuclear hazards and may have to deal with a compounding of complexity at different level. Also, under social constrain reflecting social aspect of complexity of system are added values which improve the quality of the human life.

5 Indicators

In order to develop appropriate tool for the quality presentation of complex system, it is of interest to introduce the notion of the indicators which are measuring parameters of the respective quality [22]. Before, we will introduce individual indicators the agglomeration procedure is described.

5.1. *Hierarchical Concept of Indicators*

As it was shown different complexity elements are expressed as the integral property of the system. For the determination of these elements respective model are used based on the mathematical description of the processes within the system.

Recently it has become necessary to make assessment of any system taking into a consideration the multiple attributes decision making method. It has been exercised in the number of cases the evolution of systems with criteria reflecting resource, economic, environment, technology and social aspect [23, 24, 25]. A complex (multi-attribute, multi-dimensional, multivariate, etc.) system is the system, whose quality (resources, economics, environment, technology and social) under investigation are determined by many initial indices (indicators, parameters, variables, features, characteristics, attributes, etc.). Any initial indicator is treated as the quality's, corresponding to respective criteria. It is supposed that these indices are necessary and sufficient for the systems' quality estimation [26].

An example of graph-representation of a 2-height pyramidal hierarchy of indices is pictured on the Figure 4.

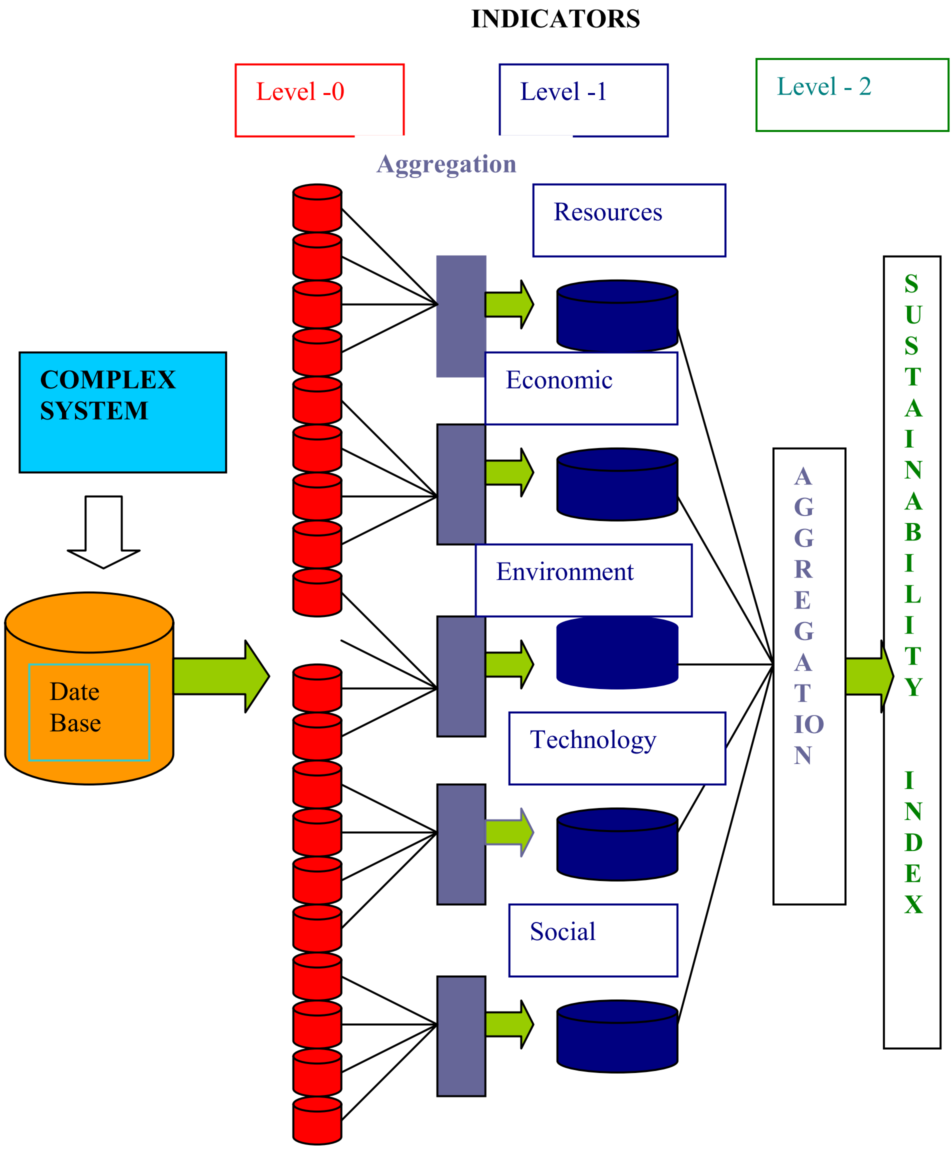

Figure 4. Graphical presentation of the algorithm for the sustainability evaluation of complex systems.

5.2. *Safety Index*

If it assumed that the sustainability indicator is time dependent function , we can take predefine time increment and determine Sustainability Index at the beginning and the end of the time increment.

In this respect we can form respective data bases reflecting individual values of the indicators for the specific time. Following the same procedure for the Sustainability Index Increment for the specific time increment we will obtain change in the Sustainability Index as measure of the Safety Index, Figure 5. If this procedure will be applied for the different time increments the results obtained will give us possibility to justify Safety Index as the property of the complex system. Introduction of block diagram is aimed to show the procedure for the definition and determination of the safety index. As it can be noticed the first step in this procedure is to define an increment of time for the collection of the basic data to be used in determination indicators.

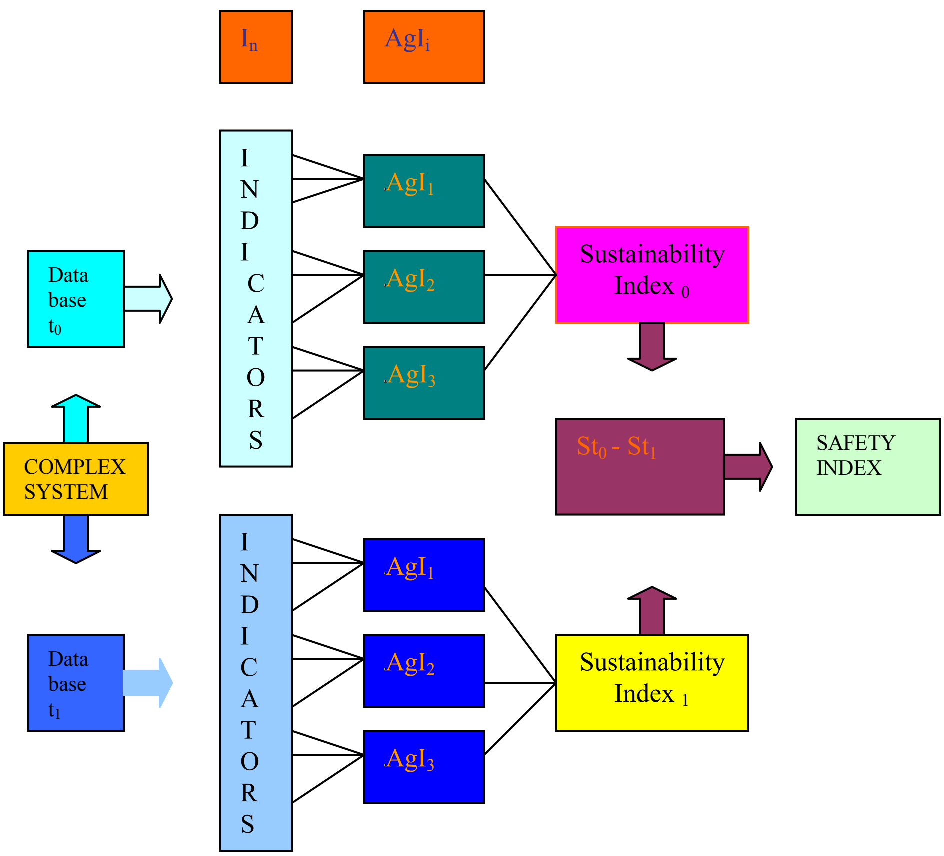

Figure 5. Block Diagram for Safety Index.

The safety in complex systems is an open question. We have described one approach to achieving this goal that has been demonstrated on several real systems, including energy environment and water systems [28, 29]. Safety, however, is not something that is simply assessed after the fact but must be built into a system. By identifying safety-related requirements and design constraints early in the development process, special design and analysis techniques can be used throughout the system life cycle to guide safe software development and evolution.

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Since the publication of »The limits to growth« as a report to the Club of Rome we know that we have to adapt to living according to a new development paradigm: Instead of unlimited economic growth which is appropriate for an open system with unlimited energy supply and natural resources we have to develop a strategy of living in a »growth limited society«. This is so since we are at the end of the »growth society« which started about 4000 years ago with the start of agriculture and about 200 years ago with the »industrial revolution« and we are for the first time in history reaching the ecological and other capacity limits of our planet. The realization of that is of a particular importance now when Europe is entering a new development cycle. This cycle is on one hand driven by demographic changes induced by an ageing population, globalization and the transfer of production to countries with cheaper labour force and on the other hand by informatics, biosciences and nanotechnology. The various possible scenarios of the future are shown and it is demonstrated that a sustainable development and/or survival scenario is achievable if certain conditions are met. Standardisation is important for sustainable development, because on one hand it assures quality of measured data on environment and indicators of sustainable development and on the other hand it helps in implementation of new environmentally friendly technologies.

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1 Introduction

Since the introduction of the sustainable development concept by the Brundtland commission in 1987 [1] and Agenda 21 as an action plan for sustainable development in 1992 [2] there have been many attempts to measure sustainability using various sustainable development indicators [3]. Sustainability implies a balanced development of economy, society and environment in such a way that development with current generation leaves at least the same or better chances for development also to future generations. Sustainability is measured by international organisations, such as United Nations or European Union (EU), with economic, social, environmental and institutional indicators [3]. There have been also many academic attempts to measure sustainability. A comprehensive overview of sustainability has been performed by the Initiative of Global Leaders of Tomorrow Environment Task Force, which created the Environmental Sustainability Index (ESI) [4, 5] and the Environmental Performance Index (EPI) [6].

Current development of Europe is driven by demographic changes induced by an ageing population, globalization and the transfer of production to countries with cheaper labour force as well as by informatics, biosciences and nanotechnology. Indeed, EU has declared that its goal is to build a knowledge-based competitive economy by 2010 and to become a knowledge-based sustainable society by the year 2025.

The two critical issues are over use of resources on one side and environmental pollution on the other side, and they are interconnected. One of the most serious environmental pollution issue is the emission of green house gases (GHG) connected with the over use of oil resources. The significance of the Kyoto protocol limiting and reducing GHG emission is more political than scientific and practical. The CO2 emissions reductions that it requires – an average of 5.4 % below 1990 levels by 2008 – 2012 - are extremely modest. The biggest emitter of green house gasses, the USA, which produces 25% of global CO2 emissions, has no plans to take part in the Kyoto agreement. Fast growing countries – China and India – have no emission limits. Also European countries which signed the Kyoto protocol, can do significantly more to decrease the use of resources and to decrease pollution. Standardization in European Union would significantly decrease the over use and pollution.

There are two important effects of standardization. On one hand standardization assures that measured data on environment are accurate, and on the other hand standardization helps in introducing new practices, which are more sustainable. The first issue has been intensively studied. The International Institute for Sustainable Development for instance issued a comprehensive review [7] to the International Organization for Standardization (ISO), which held a Social Responsibility Conference in 2004. This review focused on issues related to ISO’s role in standardization of sustainable development and contained recommendations related to next steps in the standardization process [7]. Another study was prepared by Natural Resources Canada, which demonstrated the importance of Data Standardization for Generating High Quality Earth Observation Products for Natural Resource Management [8].

In this contribution we focus on the second issue and try to answer the question how standardization can help to introduce new and more sustainable practices. We discuss a specific example of wind barriers and their use in transport. These wind barriers on one hand reduce energy use and also provide other social, environmental and economic benefits.

2 Case study example – multifunctional wind barriers

The current EU policy is insufficient to shift the current development trends toward sustainability. We argue that standardization, and optimization using best practices and policies that require implementation of environmental standards, such as IPPC, have to be formulated as EU directives. Once they are accepted within EU, their success will guarantee their spread elsewhere.

We discuss a specific example of good practice regarding wind barriers and their use in transport. These wind barriers on one hand reduce energy use and provide other social, environmental and economic benefits. The Ajdovščina-Vipava highway in Slovenia has been selected for a pilot test, because strong pulsating wind causes this highway to be closed for a significant part of the year. Figure 1 shows a map of the region where wind barriers are proposed to be built. A design of the new wind barrier has been made, which will allow the traffic to flow throughout the year, and at the same time serve as a source of renewable energy.

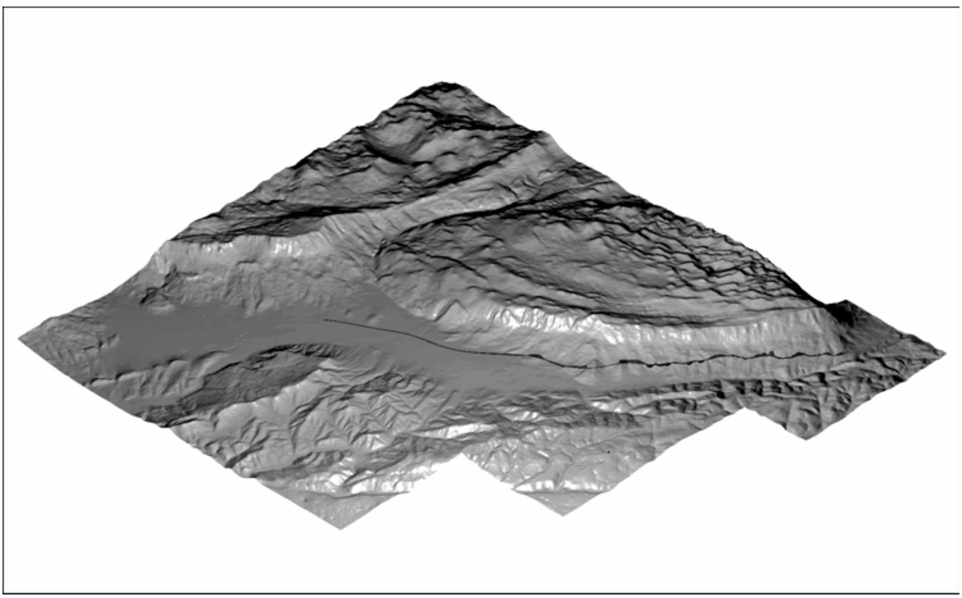

Figure 1. Map of the region where wind barriers are proposed to be built.

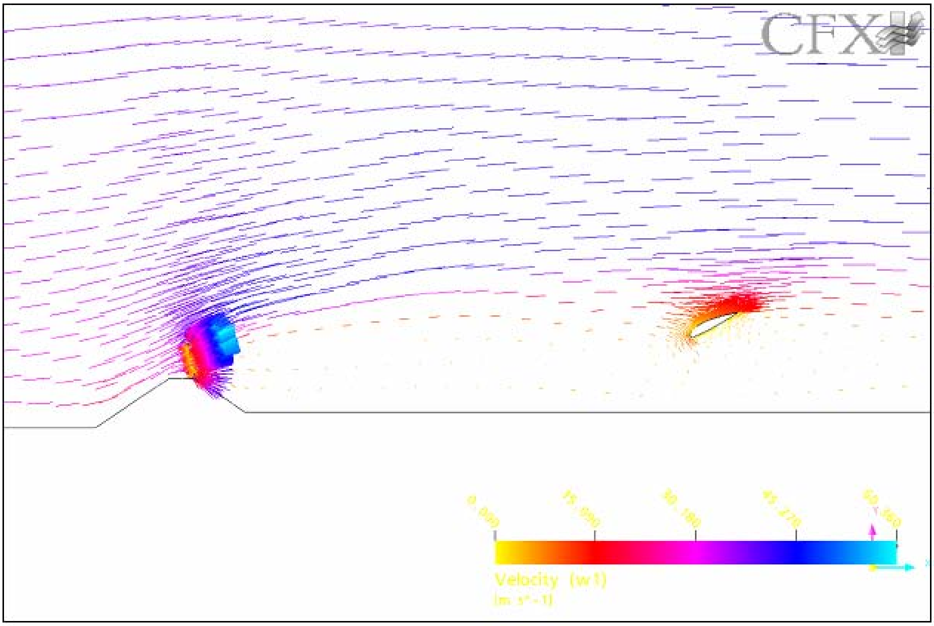

Figure 2. Wind pattern around the barrier.

Proposed design of a wind barrier is shown in Figure 2 as a cross section perpendicular to the highway. The barrier is designed as a series of wings on the side, from which the strong wind blows, and another wing on the other side for stabilization of the wind pattern. The wing system is 1.3 m high, and the wing on the other side is 1,8 m long. The system is designed so that the wind speed on the highway is reduced from the nominal speed 35 m/s below 2 m/s. All these wings are designed to be adjustable, so that they would move according to the wind pattern. Each wing would be equipped with piezoelements and solar cells. During strong winds the wings would convert wind energy into electrical energy using piezoelements. When there is no wind, the wings rotate toward the sun, so that solar cells can be efficiently used.

3 Various scenarios

Current trends without a widespread implementation of new environmental standards are unsustainable ecologically and socially as demonstrated at UN conferences in Rio de Janeiro in 1992 and confirmed in Johannesburg 2002. The business as usual is impossible. The world today is fundamentally different from the one in which the current scientific enterprise has developed [9]. There are strong couplings among biological, ecological, physical, economic, business, social, R&D and political systems. They each have distinct value systems and have evolved in a regime of weak coupling. To avoid catastrophic scenarios [9, 10] our approach has to be integrated emphasizing knowledge – business – governance intertwining.

Meadows et al. [10] developed several quantitative scenarios of global development. We tested their model with various assumptions regarding technological development and implementation of technological solutions with new environmentally friendly technologies as standards. All scenarios which don't assume implementation of new environmentally friendly technologies as standards predict a collapse of industrial production and deterioration of environment already in the first half of this century. If the current industrial civilization wants to survive without a complete breakdown of its institutions and quality of life, it is therefore vital to:

- Develop, accept and implement new environmental standards, such as for example the IPPC Directive of the European Union [11].
- Stimulate new scientific discoveries and technological implementations of ideas, which can improve the state of environment, such as multifunctional wind barriers described in the previous chapter.
- Standardize these new discoveries, so that they become common practice.

This standardization of new environmentally friendly technologies can either be achieved due to their superior economical performance or as an international agreement, such as European Union Directive or United Nations protocol.

Only if new discoveries can be standardized for global applications, there is a chance that a collapse of industrial production can be avoided.

4 Conclusion

Using a specific example of multifunctional wind barriers we demonstrated the importance of standardization for sustainable development. We further used quantitative models of development in order to demonstrate that implementation of new environmentally friendly technologies is vital for survival of current industrial civilization and its transition to sustainability. Broad implementation of these technologies can either be achieved because of their superior economic performance or with international agreements for standardization of these technologies. The example of multifunctional wind barriers demonstrates that creative ideas can lead to development of new technologies, which are both economically competitive and environmentally sustainable.

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SUSTAINABLE TECHNOLOGY TRENDS

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The environmental problems created by centuries of industrial development as well as the elimination of social disparities triggered by a globalised market-driven economic order and the re-evaluation of the western consumption patterns, require a new approach to the use of technology. The emerging new sustainable technologies should not only have the required functionality but also must be cleaner, environmentally friendly and socially acceptable. Their use should balance market profitability with environmental considerations and social accountability. The paper examines the formation of the notions of environmental and sustainable technologies which is then followed by an analysis of trends and country rankings in four specific technological groups, namely anti-pollution, environmental, renewable energy and nanotechnologies. Studies of patented technologies in the USA are used to examine how different countries fare in the development of new technologies the application of which can potentially lead to more sustainable economies.

1 Introduction

The rapid development during the industrialisation era not only created powerful economies and widespread urbanisation, it also established the authority of modern technology. For example, Engels in 1844 [1] conceptualised the power of science as the third element in the traditional land-people relationship and argued that its potential and capabilities are limitless and hence, humans can successfully resolve any resource scarcity by the means of technology. Technological advancement became and continues to be a major factor among others in making material production efficient, substituting for limited or expensive resources (including human power), allowing enormous progress in our understanding of human health and prolonging life expectancies, organising and managing people's livelihoods. The technological race was the main arena of competition between the West and the former Eastern European economies, and now continues to play a major part in the development of the North as well as in the economic aspirations of the South.

The industrial development all over the world however was plagued with environmental and social unsustainability. The deterioration of the natural environment, loss of biodiversity, climate change are happening amidst a widespread acceptance of social disparities, division of the world and concentration of power. Many see science and technology as playing a panacea role in solving the environmental problems created by centuries of industrialisation as well as in eliminating the gaps caused by a market driven economic order, where the high consumption patterns of the elite dominate "rational" behaviour and production. Irrespectively of whether you agree with the prowess of the human genius to resolve the problems with technology, it is clear that there is a need for a new type of technologies which can support the currently emerging culture of sustainability, based on a holistic view of the economic, social and environmental aspects of human activities. These technologies must be economically viable, environmentally friendly and socially acceptable. The paper examines the formation of the notions of environmental and sustainable technologies and then follows with an analysis of trends and country rankings in four specific technological groups believed to be representative of these new technologies, namely anti-pollution, environmental, renewable energy and nanotechnologies.

2 Sustainable Technologies

Some major changes in the last few decades gave raise to the understanding that sustainable development can only be achieved through the use of sustainable technologies. What are they and how can countries and companies position themselves against this trend?

The upsurge in economic globalisation in the 1980s affected not only trade, labour and financial markets but also impacted profoundly on the nature and rate of technological change. Around about the same time, environmental issues became a major concern across countries and industries. The opponents of globalisation have ample evidence of worldwide increase in environmental degradation and economic inequality (see for example Borghesi and Vercelli [2]), a major role in which has been played by technology and technological developments, such as the Green Revolution (Shiva et al. [3] write about its detrimental effect on village life in India and other developing countries) or the large increase in greenhouse gas emissions from the fossil fuel based economies. The proponents of economic globalisation, however, view it according to Tisdell [4] "as a positive force for environmental improvement and as a major factor increasing the likelihood of sustainable development through its likely boost to global investment" (p. 185), Studies, such as that by the OECD [5] claim that there are positive environmental consequences from the interconnected world economy, from the opening of the domestic markets, introduction of environmental legislation and subjecting firms to international demand patterns (including green consumerism).

The development, implementation and use of technologies have been influenced largely by the imperatives of the day and the values embedded in the organisations holding the necessary resources. A significant component of this development has been new technologies that have less impact on the environment and/or help restore environmental health. The intent of these environmental technologies is to reduce the overall ecological impact by humans and their advantages/benefits include a significant reduction in the environmental impacts of the activities of companies, agencies or people using them [6]. Companies with strong R&D capabilities and the capacity to bring innovative products and processes realised that good environmental performance can enhance market performance [7] and started to generate ranges of clean technologies. Publicly funded research, including universities, became another significant source of innovative solutions that reduce the human impact on the environment. A positive outcome of the interconnected world is the facilitated diffusion of these environmental technologies, services and technological solutions across different markets as well as industries. They became incorporated in new business practices, in the new way of marketing and designing products and production processes. Examples include close loop water collection for water recycling and reuse; photovoltaics for energy generation as a renewable energy technology; systems allowing reuse of air and oil filters as material recycling technologies; biodegradable chemicals as pollution control technology [8]. Against the debates about the Kantian principles of universal justice [9] and Foucault's reflections on centralisation of power [10], the care for the environment is seen as a luxury that only the developed rich can afford.

The sustainability agenda of the 1990s and 2000s re-emphasised concerns raised earlier during the appropriate technology movement about social responsibility in technology development (eg Schumacher in 1973 [11]). Socially responsive and environmentally-sound (benign or restorative) technological solutions are now expected to become more mainstream on commercial markets. Their number, availability and coverage of sectors and industries are increasing all the time. The renewable energy sector is seen as having an enormous potential to deliver sustainable technologies and this perspective is shared equally by government (eg Alber et al., [12] for a State of Hawaii government) and private industry (eg Yang [13] for a business perspective from Shell). The housing industry is another example of a large sector which offers opportunities for application of sustainable technologies (eg AMA Research [14]). The applications of sustainable technologies in the food market, land use, water management are other extremely important and contested areas (eg the Western Australian State Sustainability Strategy [15]). There is also a lot of hope associated with the new emerging frontier technologies as nanotechnologies which are perceived as inherently green with high potential to influence the way we do things today (eg Marinova and McAleer [16]).

While the notion and development of environmental technologies cross a wide range of science and engineering disciplines and require multidisciplinary and interdisciplinary knowledge, approach and skills, sustainable technologies are even more encompassing. They are conceptualised in a sphere which joins together integrative analytical skills, smart synthesis expressed in frontier technical solutions, and contextual understanding of the problems and implications from the existence, removal, introduction and interactions of new technologies, including environmental, social and economic dimensions. The concept of sustainability also has the effect of engaging community, not just technological experts and policy makers in value-loaded debates, as it affects the future and future generations [17].

Sustainable technological innovation views technologies as means to achieve broader aims than economic profit to include environmental restoration and conservation, social justice as well as economic prosperity and improved quality of life [18]. The sustainable technology approach also requires understanding of the interactions between technology and the social, ecological and economic systems. For example, it is not possible to look for waste management solutions without examining the nature of the goods, their production, the distribution networks, consumer choices, domestic and work practices, government policies, legislation and environmental regulations. Similarly, it is impossible to satisfy the demand for energy without analysing its nature as well as economic, social and environmental costs and benefits.

Sustainable technologies are therefore technologies which can simultaneously and synergistically include market profitability, environmental considerations and social accountability. By balancing these three aspects, they allow for sustainable practices. The market as well as society expects sustainable technology ventures to deliver in a synergistic way economic, environmental and social benefits. These innovations need to be socially acceptable and contribute to the appropriate natural resource management.

The sustainable technologies concept has enormous growth potential, both for each country and globally, and also within each separate industry or across industries. Major efforts are made specifically at a local level of governance as this is where the effect of any changes – deterioration or improvement – in the social, natural and economic environment are most immediately felt. Example of this are the efforts of the local government in the US City of Portland [19] to facilitate the introduction of sustainable technologies by establishing databases of best practices and setting up benchmarks.

Although the prevailing business attitude still is to continue with the business as usual scenario that demonstrates almost unilateral preference for economic values, the changes towards a more sustainable way of doing things are accelerating. The pressure is coming from all directions, including civil society, government and non-government organisations. It is a movement which can no longer be ignored. There is an emerging consensus that the sustainability imperatives require new approaches and new ways of thinking to respond to the current environmental and social concerns. The following are some examples of strategies adopted and consequent changes:

- Some companies are at the forefront of environmental management and sustainable technology implementation. For example, such companies have adopted the voluntary international standards ISO 14000 (covering environmental management systems, environmental auditing, environmental performance evaluation, eco-labelling and life-cycle analysis), perform triple-bottom-line accounting, or are endorsing the Factor 4 and industrial ecology principles.
- In many companies the importance of sustainability is reflected in establishing sustainability managerial positions. Their role is to direct and be responsible for the whole impact of the companies' business.
- Companies are changing their perception of the area of business they are in by adopting a long-term perspective and engagement with their clients rather than the pursuit of immediate and fast profits.
- Innovative companies and research organisations are investing at the forefront of sustainable technology development. This has resulted in intensive investment in research and development and consequently in numerous new technologies that have the potential to be sustainable.

The latter development is what constitutes the focus of interest for the rest of this paper. It can be expected that in the future all technological development will be sustainable.

However, for the time being many traditional technologies have started to incorporate environmental features which make them safer to use. There are also certain new groups of technologies that are viewed as being more encouraging to sustainability than others. These trends are discussed in the section to follow.

3 Trends in Selected Sustainable Technologies

Four representative technology groups have been chosen to examine to shed light on the quantitative trends in the development of sustainable technologies. They are anti-pollution, environmental, renewable energy and nanotechnologies. The approach used in this analysis is based on previous studies of patented technologies in the USA (see Marinova and McAleer [16], [20], [21]) and the data are derived directly from the US Patent and Trademark Office (PTO). It should be noted that as the assigning of patents to a particular group of technologies is done on the basis of keywords (rather than through a thorough analysis of the patents' descriptions and specifications), the actual numbers are of informative value. They are however robust enough to outline trends and changes that have happened over a 27-year period of analysis, namely between 1975 and 2002.

The patent data are by date of patent application, not date of issue which tends to distort technological trends. It takes at least two years after an application is lodged for a patent to be issued, and in some cases this delay can be as long as 10 years. The data for 1975-1999 were extracted from the US PTO database on 8 April 2005, and for 2000-2002 on 1 July 2006. As time goes patent numbers for recent years are likely to slightly increase as more delayed applications are being approved.

The first group, namely anti-pollution technologies, is traditionally perceived as a reaction to fix the damage or restore environmental health. Figures 1 and 2 show that although the overall number of anti-pollution technologies has been increasing since the mid 1980s (see Figure 1) their share of all patented technologies has dropped (see Figure 2). Most possible explanation of this is that pollution prevention has become a mainstream requirement for technology development rather than end-of-the pipe solution.

The second group (as presented in Figures 3 and 4) covers broadly technologies that are designed to benefit or restore the ecology. The absolute and relative numbers of these environmental technologies have been steadily increasing until the mid 1990s and then have levelled off. Some concern can be raised in relation to the issue that their relative share in the overall patented technologies in the USA has remained low at below 2.5% and has dropped to around 1.9% in most recent years. If a significant shift towards sustainability is expected to occur, then more prominent technology development activities should be observed. However, a possible explanation for the relatively low levels of patenting of environmental technologies can be found in the fact that sustainability often requires technological solutions which are locally grounded. Their application is restricted to the specific conditions of the locality and linked to geo-, climate, biodiversity and cultural factors and are not easily transferable; hence the redundancy of the need for patenting.

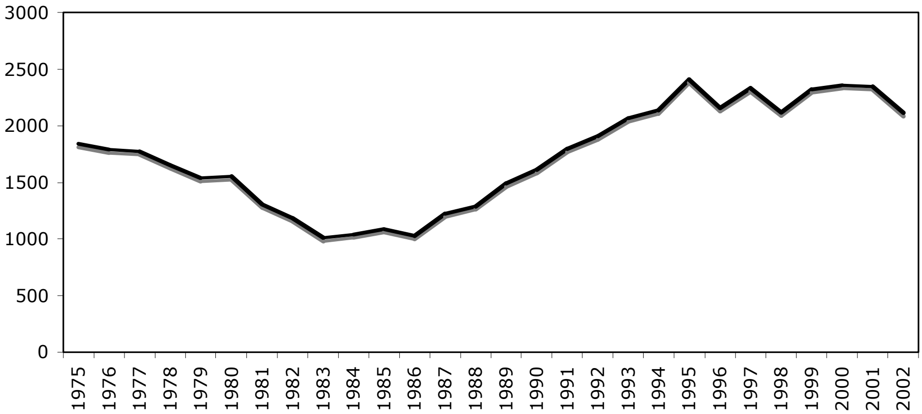

Figure 1. Annual US anti-pollution patents, 19752002.

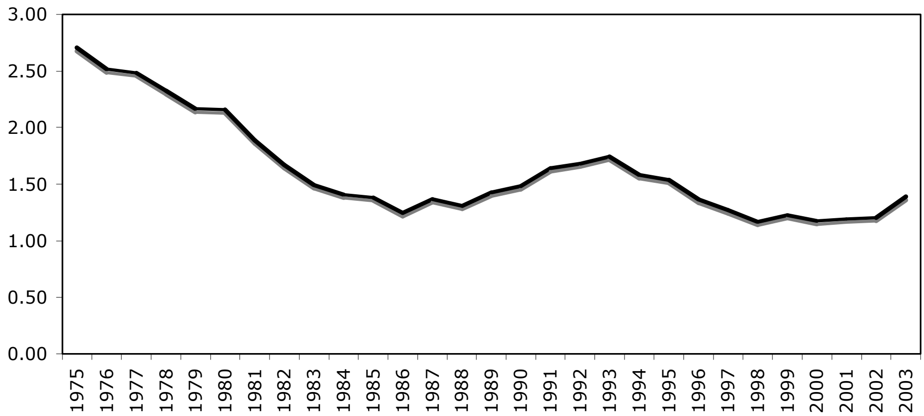

Figure 2. Share of anti-pollution to total US patents (%), 1975–2002.

The group of renewable energy technologies comprises the wide range of solar, wind, wave, tide, geothermal, hydro and biogas patented energy solutions. During the 27-year period, their absolute numbers have been slightly on the increase since the late 1980s (see Figure 5), however their relative share has experienced a significant drop from 1.4% to below 0.6% and only recently has slightly increased to the low 0.7% (see Figure 6).

The last group of technologies analysed, namely nanotechnologies, are very different in nature as far as sustainability is concerned. These technologies are perceived to be inherently ecological and to have a great future potential in many sectors such as medicine, agriculture, manufacturing, construction, transport and communications among others. They typically use few resources and, for example, can process all types of waste or be used in preventive medicine [18]. The absolute number and relative shares of these technologies has dramatically increased in recent years (see Figures 7 and 8). Currently their share in new patented technology is just below 4%. Whether the use of nanotechnologies by society, companies and individuals will lead towards a more sustainable way of living is something yet to be seen and will depend on how deeply the sustainability culture has been adopted as a main value system.

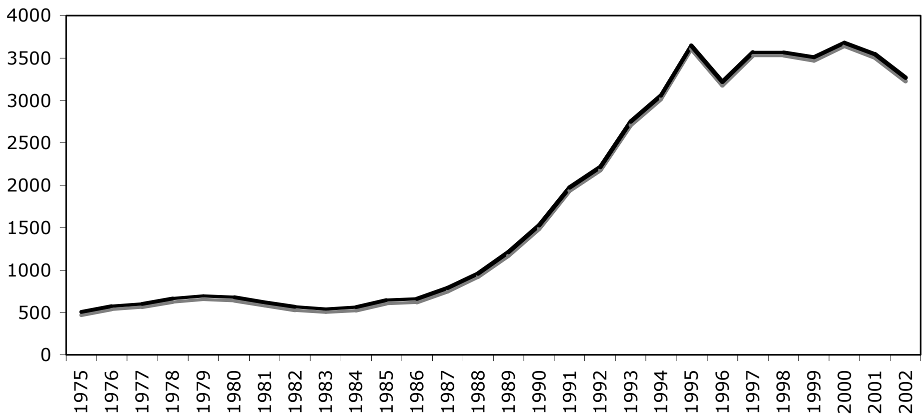

Figure 3. Annual US environmental patents, 1975–2 002.

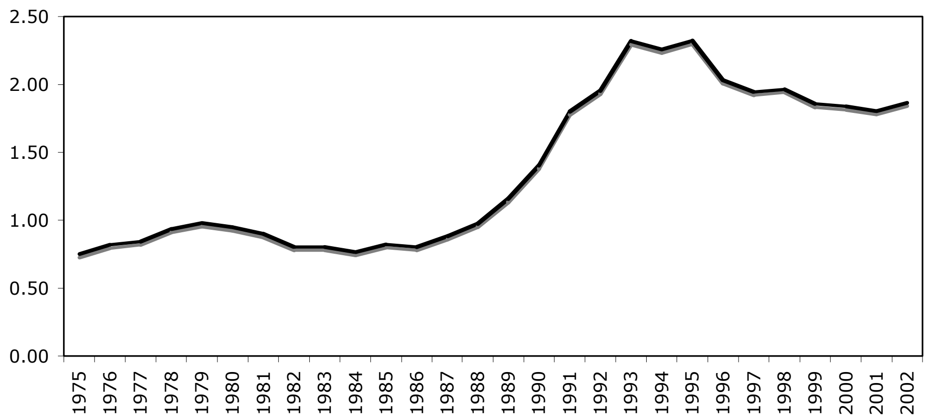

Figure 4. Share of environmental to total US patents (%), 1975–2 002.

4 Country Comparisons

It is also interesting to examine how different countries fare in the development of these new technologies the application of which can potentially lead to more sustainable economies. Table 1 presents comparative data on a national level for the four groups of technologies for the top twelve foreign countries patenting in the USA. The USA itself is not included due to disparities between comparing domestic and international patenting (the US performance would be the best in all three categories but this country

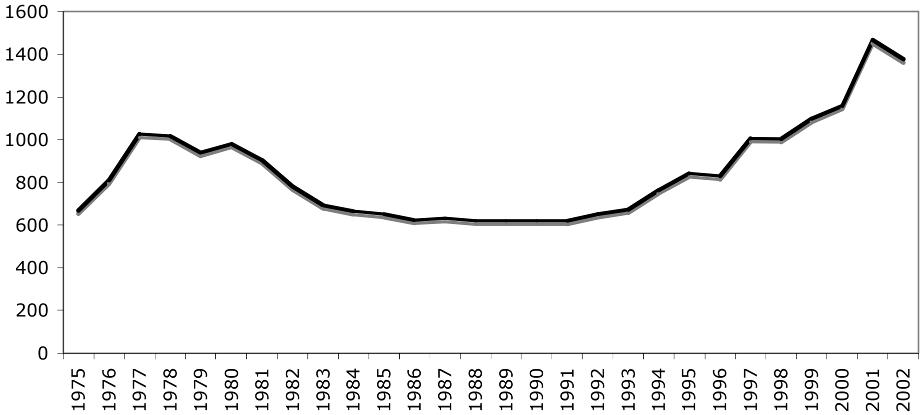

Figure 5. Annual US renewable energy patents, 1975–2002.

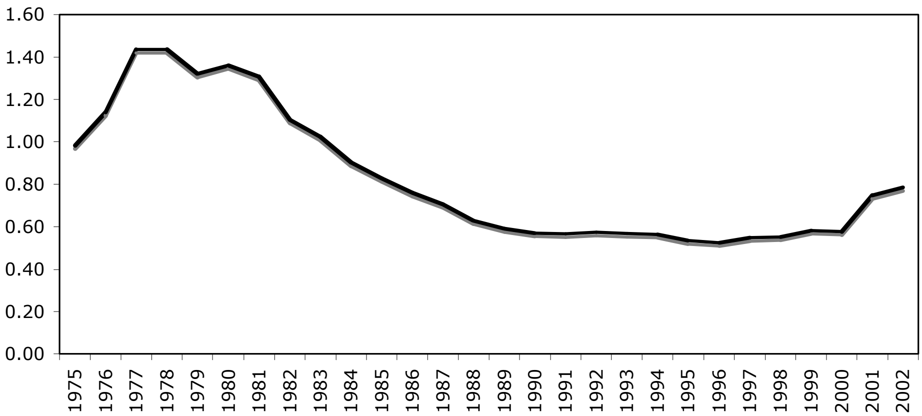

Figure 6. Share of renewable energy to total US patents (%), 1975 – 2002.

also has the advantage of performing in a domestic market). The ranking of the countries is based on their share of US patents – as a measure for their global presence, technological specialisation index – as a measure of the national importance of the technologies and proximity to the market – as a measure of commercialisation (for further explanation, see Marinova [22]). It is estimated that around 50% of all patents registered in the USA originate from foreign countries [23]. During the 1975-2002 period analysed, the top twelve foreign countries cover 45% of all anti-pollution technologies, 29% in nanotechnology, 27% in environmental technologies and 26% in renewable energy. This is also indicative of the relative importance which foreign countries assign to the implementation of the sustainability concept in the American market. Japan ranks first in anti-pollution technologies, second in renewable energy and nanotechnologies and third in environmental technologies. France is first in nano- and renewable energy technologies and Germany is first in environmental technologies.

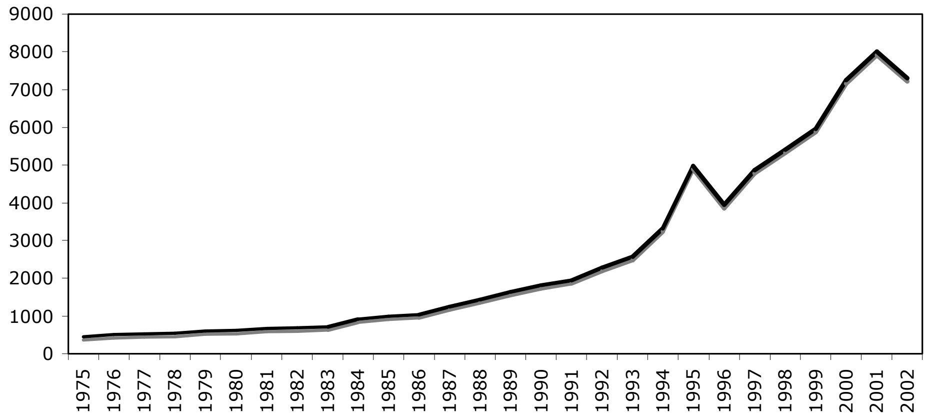

Figure 7. Annual US nanotechnology patents, 1975–2002.

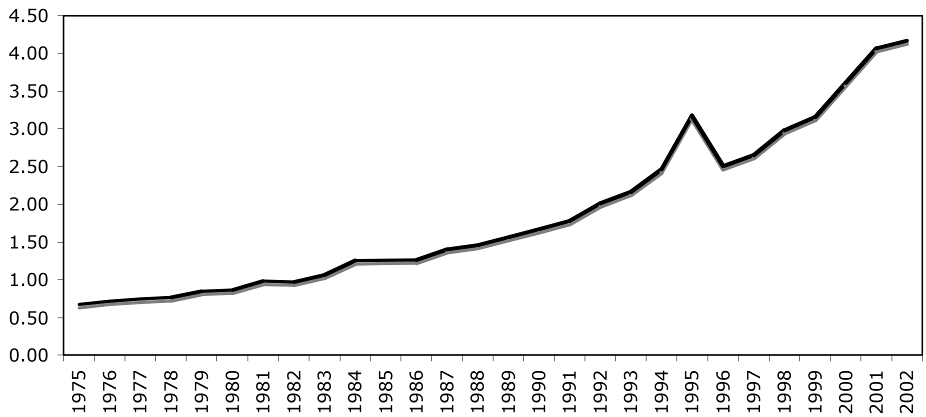

Figure 8. Share of nanotechnology to total US patents (%), 1975–2002.

5 Conclusion

The study reveals that although around for two decades, the practical adoption of the concept of sustainable technologies has only just started. These technologies still represent a very small share of the new patents. On the one hand, the type of technologies patenting is very informative as to where the economically strong economies are going and as to what their priorities are. However, it also raises very important issues about the disparity between the ones who can afford to pay for a more sustainable way of living and the ones who cannot.

Table 1. Country rankings in technology development, 1975-2002

Country	Anti-pollution technologies	Environmental technologies	Renewable energy	Nano technologies
Australia	9	3	3	5
Canada	6	5	6	5
France	2	10	1	1
Germany	3	1	3	3
Italy	3	8	9	10
Japan	1	3	2	2
Korea	5	10	10	8
Netherlands	7	2	11	4
Sweden	10	8	8	12
Switzerland	10	6	5	9
Taiwan	7	12	12	10
UK	12	7	7	7

The efforts of the global community to combat the problems of social justice, poverty and environmental degradation in the pursuit of a better quality of life will be supported and dramatically enhanced by smart and breakthrough technological developments. We are witnessing the emergence of the new sustainable technologies which will contribute to the development of the ethics, values and practices of the new sustainability culture but it will be up to the global community to make the best use of them for the sustainability of all people on the planet Earth.

Acknowledgement

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ANALYSIS OF SUSTAINABILITY INDICATORS USING DATA-DRIVEN SPACE MODELS

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Space Models are new space geometries that are created to emphasize the particularities of the geo-referenced data being analyzed. A Space Model integrates groups of regions that present similar behavior attending to a specific characteristic. Each group represents a cluster aggregating regions that are similar regarding to the analyzed characteristic, and regions in different clusters are as dissimilar as possible. This paper proposes the creation of Space Models, through the STICH (*Space Models Identification Through Hierarchical Clustering*) algorithm, as an alternative approach for data visualization, where the geometry of the maps is created from the data itself. The achieved results are illustrated through a set of examples that are compared with conventional representations, showing that Space Models provide real added-value over conventional approaches, namely by facilitating the identification of peculiarities in the data.

1 Introduction

Maps are used in many application areas to support the visualization of geo-referenced data. However, the geometry explicit in each map is defined for or with a specific purpose, being sometimes later used in applications for which it was not conceived. This is often the case with maps representing administrative subdivisions of the geographic space. Administrative subdivisions inside a country – parishes, municipalities, and districts, for example – are defined following specific criteria and an accumulated number of changes along the years, and not following a natural division of the space. They are later used as a reference for data analysis, even when they are not the most suitable resource for that. As an example, consider the ‘Emissions of greenhouse gases’ indicator distribution across the 15 European countries[a] represented in Figure 1, and collected at NUTS II level.

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[a] These were the 15 European countries that integrated the European Union until April 2004.

In the map shown in Figure 1, the conventional method for data visualization was used. Since the data is available at NUTS II level, the obvious choice for visualization is to use a map with the NUTS II geometry, classify the data values within a given number of classes (6 in this case), and paint the NUTS II regions accordingly to the class of the data value associated to each region. Geographic Information System (GIS) tools provide means to build these maps automatically, including the classification of the data values in different classes using a few different methods (Equal Interval, Quantile, Natural Breaks (Jenks), Standard Deviation).

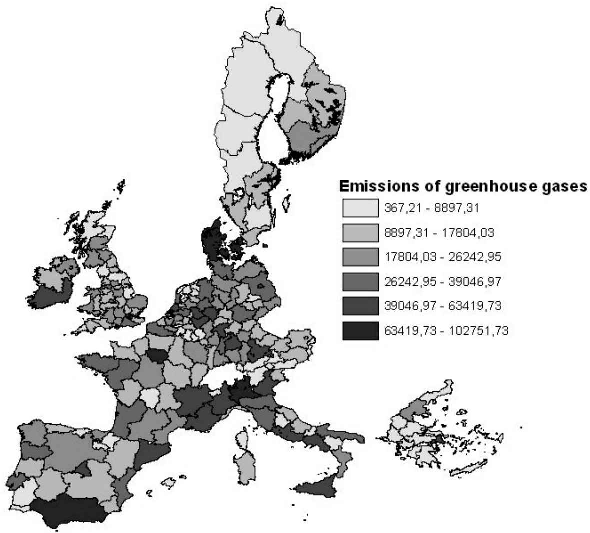

Figure 1. ‘Emissions of greenhouse gases’ indicator across Europe.

The first problem with this approach is that the NUTS II regions are of very different sizes: large regions in countries like Spain and Sweden, and very small regions in countries like Germany and Belgium. The second problem is the choice for the number of classes used to group the data values (and consequently the number of different colors used to paint the regions). In this example, regions with data values between 367,20 and 8897,31 are classified within the same class (more than an order of magnitude between the lower and upper limits). Therefore, the observation of the map does not provide any information about what regions are close to the lower limit (performing better) or close to the upper limit (performing worst). To observe these differences, a larger number of classes must be used, probably turning the map very confusing and loosing the whole picture. Finally, even with a considerable small number of classes (6 in this example), this map does not clearly shows the best and worst regions in terms of the indicator under analysis.

To overcome these limitations this work describes an approach for the identification of Space Models - new space geometries that are created to emphasize the particularities of geo-referenced data. Each Space Model integrates groups of regions that present similar behavior attending to a specific characteristic. Each group represents a cluster aggregating regions that are similar regarding to the analyzed characteristic, and regions in different clusters are as dissimilar as possible.

In order to identify Space Models the hierarchical clustering algorithm STICH – *Space Models Identification Through Hierarchical Clustering* – was developed, allowing the identification of sets of regions with similar behavior.

Space Models are of great importance for the analysis of indicators (environmental or social, for instance) associated to regions and to understand the main differences between these regions. This is the objective of the EPSILON (*Environmental Policy via Sustainability Indicators on a European-wide NUTS III Level*) project[b], in which the collected sustainability indicators are analyzed in order to identify regions with similar behavior, and regions that exhibit different trends in data, in order to achieve a sustainable development across Europe. This project contributed to the better understanding of the European Environmental Quality and Quality of Life, by delivering a tool that generates environmental sustainability indices at NUTS-III level. The work described in this paper was developed as part of the EPSILON project and was integrated into that tool as an added-value functionality for data analysis.

This paper is organized as follows. In the next section, the fundamentals of Space Models are introduced and the algorithm used for their creation is described. Then, the application of Space Models in the analysis of sustainability indicators is presented through a set of examples. These examples compare the results obtained through the use of Space Models with the results that are achieved by conventional visualization approaches based on administrative maps. The following section is dedicated to the description of the Space Models Tool implementation and its integration into the EPSILON Tool. Finally, we present some concluding remarks.

2 Space Models

Human beings mentally use space models to simplify reality and to perform spatial reasoning more effectively. When we look to the birth rate of the several districts of a country and try to analyze the available data, our first thought is to group districts with similar birth rate. This procedure allows us the creation of a space model.

Space Models are new geometries of the space that are created to emphasize particularities of the analyzed data. A Space Model integrates groups of regions that present similar behavior attending to a specific characteristic explicit in the data. Each group represents a cluster aggregating regions that are similar regarding to the analyzed characteristic. Regions in different clusters must be as dissimilar as possible. Besides the role of Space Models in data analysis, their creation also allow their use as a mean for data visualization when the available maps are not suitable or do not fit specific purposes.

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[b] A project founded by the European Commission through the IST program (contract IST-2001-32389). More details can be found in http://www.sustainability4europe.org/.

2.1. *Concepts associated to Space Models*

The creation of Space Models [1, 2] through clustering techniques [3, 4, 5] allows the identification of groups of regions that emerge from the analyzed data and not groups of regions that are imposed by either analysis techniques or human constraints.

The process of creation of Space Models presented in this paper is completely autonomous and automatic (its algorithm is resumed in the next subsection) and assumes several assumptions that guarantee the quality of the obtained Space Models. The principles are:

- Space Models must be created from the data values available for analysis, and no constraints can be imposed for their identification.
- The created Space Models must be the same, independently of the order by which the available data is processed in the clustering process.
- Space Models can include clusters of different shapes and sizes.
- Space Models must be independent of specific domain knowledge, like the specification of the final number of clusters.

2.2. *The identification of Space Models with the STICH algorithm*

The STICH algorithm [1, 2] is based on an iterative process in which the several regions are grouped according to their similarity with respect to a specific characteristic. In each step of this process the clusters are formed joining the *k* most similar regions, being *k* a value identified from the data and dependent of each cluster.

This iterative process starts with all regions in different clusters, i.e. each region constitutes a cluster, and ends with all regions grouped into the same cluster. As a hierarchical clustering algorithm it allows the identification of several Space Models, one at each iteration of the clustering process.

The formal specification of STICH can be found in [1, 2]. Figure 2 depicts a simple example in which the iterative process of STICH and the clusters identification is exemplified. In this example, 5 steps were needed to aggregate all data into one final cluster. At each step different data aggregations are obtained based on the calculation of the Similarity Matrix of the regions. This matrix contains all the distances existing between each pair of regions. After this calculation STICH identifies the *k-nearest-neighbors* of each region, being *k* a value that can be different from one region to another (for more details see [1, 2]). The average of the *k-nearest-neighbors* of each region is calculated and the region is afterwards assigned to the cluster in which it appears with the minimum *k-nearest-neighbor* average. At this point new clusters are obtained and new centroids are calculated for them.

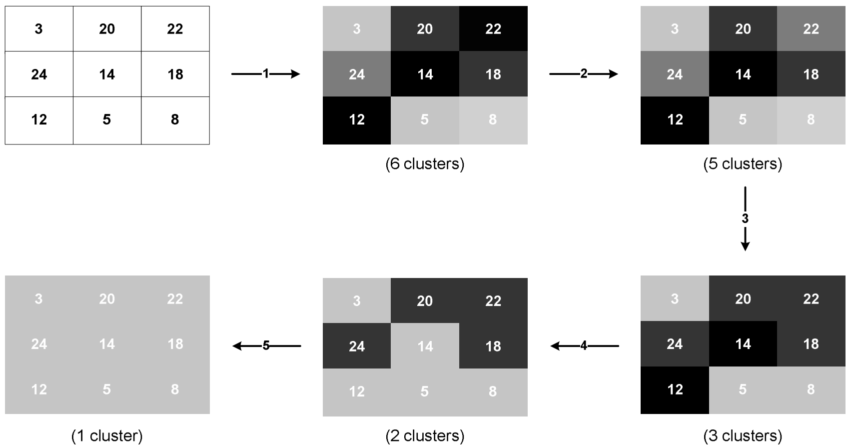

Figure 2. The clustering process of STICH.

3 Space Models in Sustainability Development

The work described in this paper, including the STICH algorithm, was developed within the framework of the EPSILON project with the aim of turning the analysis and visualization of sustainability indicators easier and more powerful. Although Space Models can be used in many application areas, in this section we present some examples within the area of sustainability indicators analysis. With these examples, some of the benefits of Space Models are demonstrated and compared with conventional approaches based on administrative maps. However, note that conventional techniques continue to be useful in many scenarios, and that Space Models approaches are, in many situations, a complement to these techniques.

Space Models created by using the STICH algorithm have some characteristics that are illustrated in the following examples, namely:

- They facilitate the identification of peculiarities in the analyzed data by highlighting regions where the geo-reference data is considerably different from the average. This allows the easy identification of regions with particular problems or regions that perform much better than others for a given indicator.
- The same data can be visualized at different levels of aggregation, corresponding to different Space Models, where the number of clusters and their limits are extracted from the data itself. These different levels of aggregation allow the analysis of the same data from a very detailed (although maybe confusing) level to a very broad level (less detail) without hiding the most different regions.
- A Space Model created from a given indicator can be used to assist on the analysis of another indicator.

To illustrate these characteristics, some data was extracted from the EPSILON database and used to create Space Models examples. The selected datasets are described next.

3.1. *The data available at the EPSILON project*

One of the outputs of the EPSILON project is a database that stores a large amount of information related to the sustainable development assessment across 15 European countries. The data in this database reflects the sustainability model developed by the project and is organized accordingly to a 4x4x4 structure: four pillars (Economic, Environmental, Institutional and Social), four themes per pillar and four sub-themes per theme. Each sub-theme is supported by a number of indicators and sub-indicators from where the corresponding value is calculated. Additionally, the database includes a number of quality assessment parameters that provide information about the quality of the data. This structure is replicated at four levels of detail (NUTS 0 to NUTS III) with different amounts of data for each level. For more information on the sustainability model developed by the project see [6].

The data used in the examples described below was extracted from the EPSILON database. The first selected dataset (dataset 1) is the ‘Soil Toxicity Index’ indicator distribution across the 15 European countries collected at NUTS I level. This dataset has a total number of 74 records. The second dataset (dataset 2) is the ‘Groundwater Quality’ indicator distribution across the 15 European countries collected at NUTS I level. This indicator represents the quality of the groundwater by means of the level of hazardous substances. This dataset has a total number of 74 records. The third example uses two datasets (datasets 3 and 4): one with the indicator ‘Average number of units in all economic activities’ (activities such as, mining, quarrying, manufacturing, electricity, gas, transport, restaurants, etc.), and the other with the indicator ‘Emissions of greenhouse gases’. These two dataset are available at NUTS II level and have 204 records each.

3.2. *The Space Models obtained through the STICH algorithm*

This section describes some examples of Space Models obtained with the STICH algorithm for the datasets identified above.

Figure 3 presents a Space Model obtained by the STICH algorithm after grouping the dataset 1 data values in 4 clusters. Note that the number of clusters is not an initial parameter of the STICH algorithm – the Space Model with 4 clusters was chosen among all the Space Models created by the STICH algorithm (this Space Model was obtained at the 19th iteration of the clustering process).

This example shows that the Space Model obtained by the STICH algorithm highlight a region (the one formed by two NUTS I regions, DK0 and DE3, marked with two circles) where the average value of the ‘Soil Toxicity Index’ is much lower than the same value in all other regions. This allows the easy and immediate identification of the areas that perform much better than all others in terms of this indicator. In Figure 4, a conventional map, with the data values classified in 4 classes, is presented. With this classification, some important information is lost.

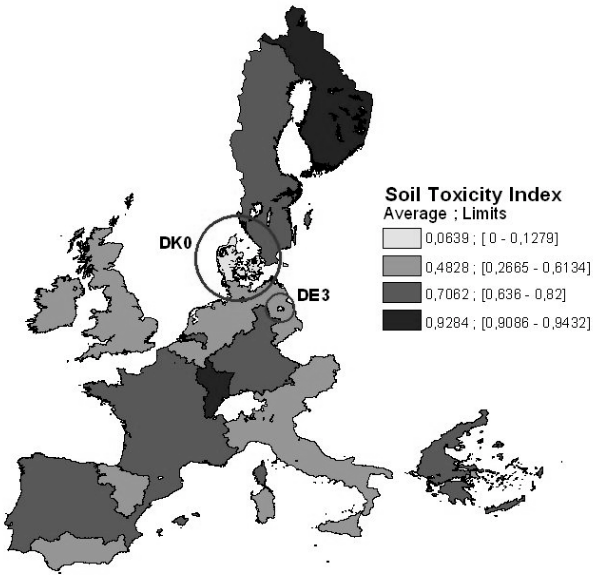

Figure 3. Space Model obtained by STICH.

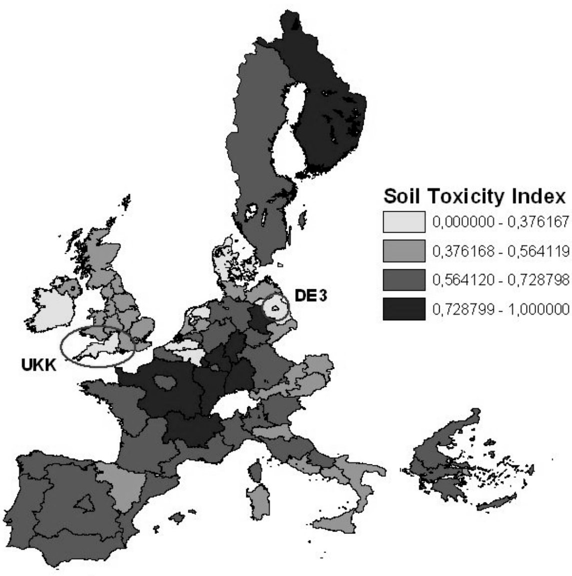

Figure 4. The same data using Natural Breaks classification of the map in 4 classes.

For example, note that the region DE3 belonging to the lower class in Figure 3, is now (in Figure 4) aggregated to other regions for which the performance in terms of the analyzed indicator is much worse. In this particular case, regions like DE3 are displayed with the same performance as UKK. However, the first one has a value of 0 while the last has a value of 0,376167. In summary, the map shown in Figure 3 allows a more easy identification of the most relevant (best and worst) cases, therefore overcoming the second problem identified in the map shown in Figure 1.

The next two figures (Figures 5 and 6) shows the same data (dataset 2) at different levels of aggregation, that is, different Space Models with different number of clusters (11 and 3 clusters respectively) and different limits for each cluster. These two Space Models correspond to the output of the clustering process at the end of two different iterations. This example illustrates the versatility of the Space Models approach.

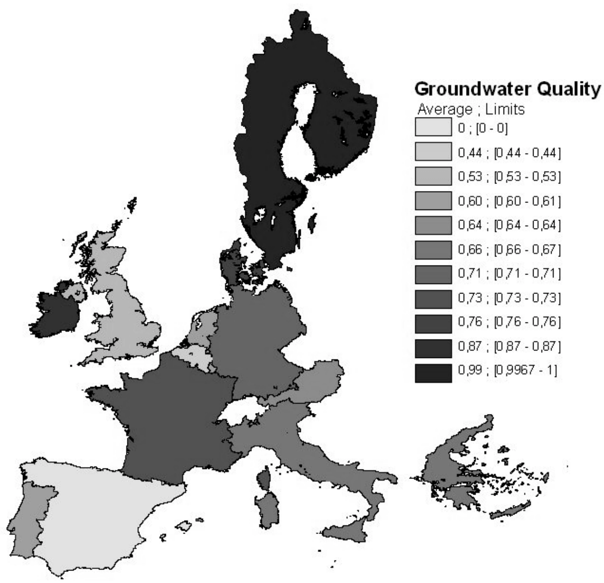

Figure 5. Space Model obtained by STICH at the 2nd iteration.

By choosing the appropriate iteration of the clustering process, the user is given the opportunity to analyze the same data at different levels: from a very detailed analysis to a broad view of the data. Moreover, with this approach, the regions that are more different than the others are not hidden by the choice of a small number of clusters (broader view in Figure 6). Note that, in this example, Spain stills highlighted as the best region, even when only three clusters are considered.

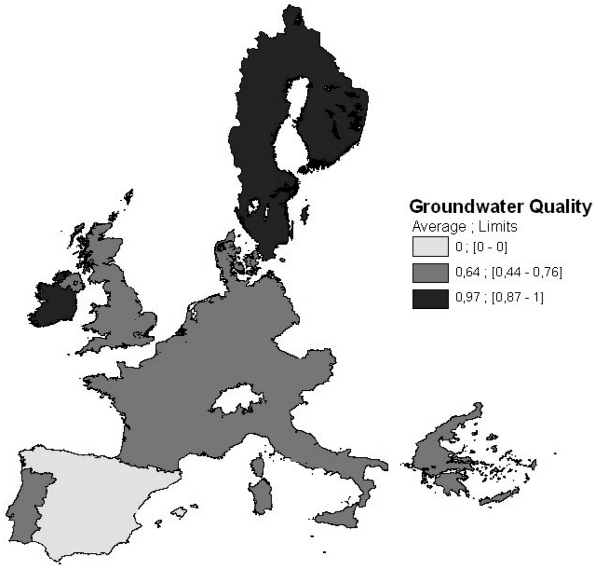

Figure 6. Space Model obtained by STICH at the 9th iteration.

The next example shows how a Space Model created from a given indicator – the 'Emissions of greenhouse gases' indicator at NUTS II level (shown in Figure 7) – can be used to assist on the analysis of another indicator – the 'Average number of units in all economic activities' indicator also at NUTS II level (shown in Figure 8).

In this example, the 'Emissions of greenhouse gases' indicator was used to create a Space Model. Then, the data related to the 'Average number of units in all economic activities' indicator was grouped exactly the same way (the same original regions) as the STICH algorithm did for the first indicator. Finally, this aggregated data was shown on top of the created Space Model.

The indicator analyzed in Figure 8 is related to the average units of all activities such as, mining, quarrying, manufacturing, electricity, gas, transport, restaurants, etc. It is therefore expected that the regions with more activities be more favorable to the emissions of greenhouse gases. Actually, as seen in Figure 8, the darker regions (regions with high number of activities) are closely related to the darker regions in Figure 7[c] (regions with high emissions of greenhouse gases). In summary, this usage of the STICH approach facilitates the cross analysis of related indicators.

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[c] The Space Model presented in Figure 7 can also be compared with the map in Figure 1 that represents the normal classification of the European Countries in 6 classes for the same dataset.

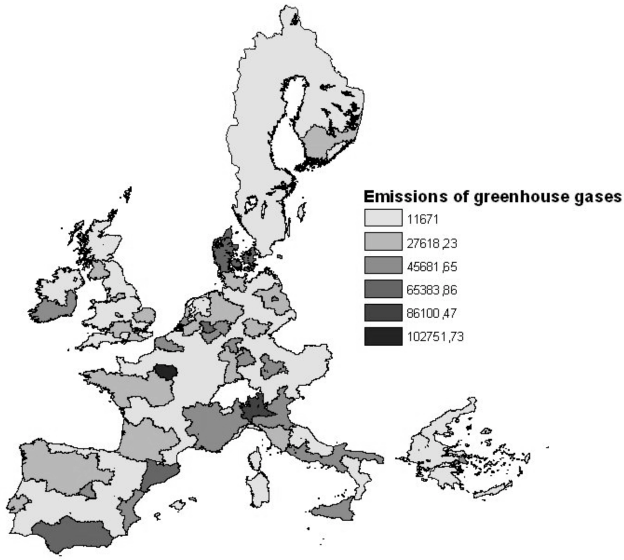

Figure 7. Space Model obtained by STICH for the indicator 'Emissions of greenhouse gases'.

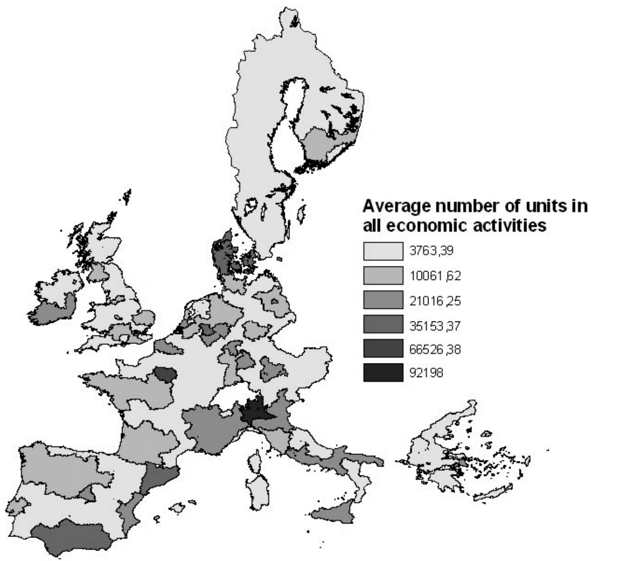

Figure 8. Analysis of the indicator 'Average number of units in all economic activities' in the Space Model obtained for the indicator 'Emissions of greenhouse gases'.

4 Technological characterization

The results described in the previous section were obtained from an implementation of the STICH algorithm called Space Models Tool – SM-Tool. The SM-Tool is a software module implemented in Visual Basic for Applications (VBA), the language embedded in the ESRI ArcView 8.2 (the Geographic Information System adopted by the project). The implementation of the STICH algorithm included in this module was developed as a set of DLL's (Dynamic Link Libraries) implemented in Visual Basic 6.0 (VB6). The result is a functionality that can be easily added to the ArcView working environment to perform data analysis. More detailed information about the implementation of the SM-Tool is available in [7].

The same set of DLL's, implementing the STICH algorithm, were integrated into the EPSILON Web Tool being developed by the project. This Web tool, available in the Internet (http://141.40.224.68/epsilonproject) using a simple browser, provide the possibility for users to perform benchmarking between different countries regarding their sustainable development. The benchmarking is supported by all the data available in the EPSILON database.

Figure 9 presents the EPSILON Web Tool in a clustering task, using the SM-Tool. In this figure it is possible to see the results of the data clustering in a specific iteration of this process. The user has the possibility to indicate the Space Model that wants to see, selecting a specific iteration in the iteration bar (each iteration is represented by a rectangle in the right-up corner of the map).

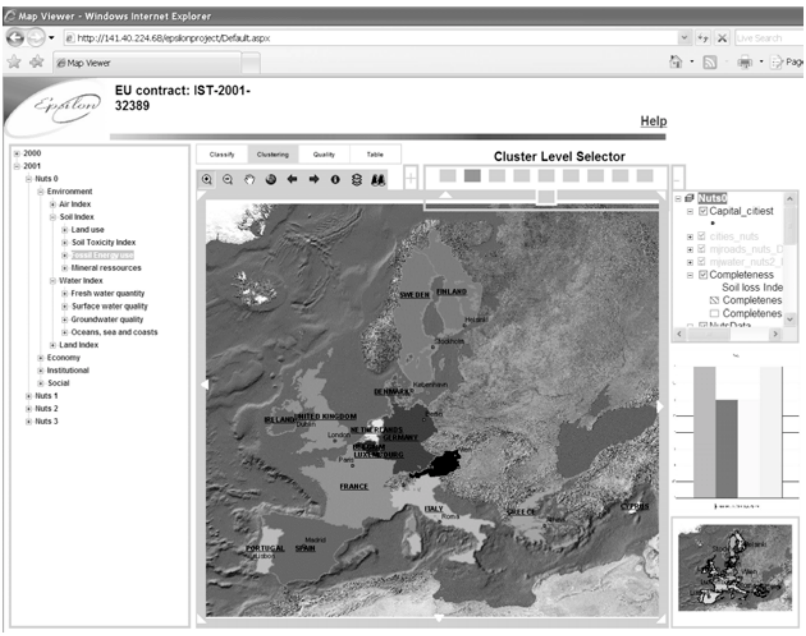

Figure 9. The EPSILON Web Tool.

5 Conclusion

In this paper, a new technique for geo-referenced data analysis and visualization, based on a clustering algorithm, was presented. This technique, available through a Space Models Tool, was developed within the context of the EPSILON project and was integrated into the EPSILON Web Tool developed by the project. The benefits of this technique were demonstrated through a set of examples oriented towards the analysis and visualization of sustainability indicators. These examples and other results have shown that the described technique provides real added-value over conventional approaches.

Nomenclature

EPSILON – *Environmental Policy via Sustainability Indicators on a European-wide NUTS III Level*
NUTS – *Nomenclature of Terrestrial Units for Statistics*
STICH – *Space Models Identification Through Hierarchical Clustering*

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ENHANCING THE INDICATORS OF SUSTAINABLE DEVELOPMENT OF THE COASTAL ZONE

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The paper analyses indicators of sustainable development in coastal zone. Indicators of the UN Commission on Sustainable Development as well as regional indicators of the European Environmental Agency are addressed. Implementation of indicators in the Republic of Croatia is discussed, both at national and local level in the Littoral Mountain County. Furthermore, paper reviews the application of indicators and the methods of reporting in the Republic of Croatia with particular reference to the Littoral-Mountain County.

1 The Concept and Function of Indicators of Sustainable Development

Pollution in coastal zone is the result of unplanned development, the collapse of traditional activities, coastal erosion and the lack of appropriate communication and transport networks. Regional seas are confronted with various coastal pressures [1], and at the same time the data concerning loads in the Mediterranean are insufficient [2].

In dealing with integrated coastal area management it is necessary to address the interaction of coastal systems and the associated social benefit. Namely, coastal area management in fact involves the analysis of a multitude of social, economic and environmental data as well as the decision-making aimed at sustainable development on the basis of complete information, in the process of open consultation with all parties concerned.

Preliminary issue is the appropriate definition of the concept of an indicator, bearing in mind that the terms such as measure, variable, parameter and index can be found in literature. In that it is necessary to point out that an indicator is used to describe the effort in building empirical approach to understanding the dynamics of coastal systems. Therefore, the indicator is a statistical parameter which, traced in time, extends data concerning the trends in development of the state of certain phenomenon, whereby its significance lays even beyond the scope of the very statistics.

Therefore indicators may transmit the perception of natural and social science into manageable information which facilitates the decision-making process.

A system of criteria [3] is, as a filter, used at each stage of selection and development of key indicators. Therefore quality indicators are sensitive to change and are supported by reliable and available data which users can understand and accept.

According to OECD [4] successful indicator should:

- reduce the number of measurements which would normally be necessary to accurately present the state, and

- simplify the procedure of reporting to the management, shareholders and the community.

2 Applying the Driver-Pressure-State-Impact-Response System in an Integrated Coastal Zone

When applying the driver-pressure-state-impact-response system (DPSIR) to integrated coastal zone management, the indicators may be classified as follows [5]:

- **Drivers** represent large-scale socio-economic conditions and sectoral trends such as patterns of use of coastal land and its cover, or growth and development of coastal industries.
- **Pressure** such as patterns of modification of coastal swamps, input of industrial POPs/metal and fertilizer use in coastal watersheds may have a direct impact on the quality of coastal environment.
- Indicators of **state** describe visible changes in dynamics of coastal environment and functions describing the coastal environment.
- **Impacts** represent direct variations of the measured value of social benefit associated with environmental conditions such as cost of the disease transmitted by the sea, lost value of the beach for recreational bathing or losses of value in terms of commercial fishing due to polluters load.
- **Responses** are defined as an institutional response to system changes (originally actuated by changes in state and impact indicators).

3 Indicators of the UN Commission for Sustainable Development

UN Commission for sustainable development (CSD) projected the development of highly aggregated indicators by engaging the experts from all sectors of the economy, social and natural sciences and politics, as well as by involving non-governmental organisations and considering the attitudes of native population.
In total 58 indicators are included in the core set of indicators of sustainable development. The theme oceans, seas and coasts are divided into two thematic sub-themes – coastal zone and fisheries. Indicators of the sub-theme coastal zone are **algae concentration in coastal waters** and the **percent of total population living in coastal areas** [6]. The alternative or supplementary indicator for the algae concentration in coastal waters is the bacterial level in coastal bathing waters.
Said core set of indicators represent the basis for national governments to develop their own programmes for indicators and for monitoring their development. The states shall have to demonstrate the flexibility and judgement in their efforts to develop national system of indicators of sustainable development.

4 Indicators of the European Environmental Agency (EEA)

Although the majority of EEA indicators [7] in the theme ***water*** are indirectly or directly related to coasts area and the sea, coastal waters are particularly addressed by core indicators

bathing water quality, chlorophyll in transitional, coastal and marine waters, nutrients in transitional, coastal and marine waters, urban waste water treatment, and other indicators **accidental oil spills from marine shipping, chlorophyll-a concentration in transitional, coastal and marine waters, classification of coastal waters, discharge of oil from refineries and offshore installations, frequency of low bottom oxygen concentrations in coastal and marine waters, hazardous substances in marine organisms, illegal discharges of oil at sea, loads of hazardous substances to coastal waters, nutrients in coastal waters, phytoplankton, algae in transitional and coastal waters, saltwater intrusion, source apportionment and loads of nutrients to coastal waters** and **trends in aquacultures production, and newly introduced cultured and associated species in European Seas.**

The system of EEA indicators in the theme ***coasts and seas*** [8] also includes core indicators dealing with aquaculture and fisheries as well as other indicators **hazardous substances in mussels in north-east Atlantic** and i**nput of hazardous substances in north-east Atlantic.**

As from 2001, EEA in its regular annual issue Environmental Signals publishes the indicators dealing with coastal sea [9,10].

Information system Eurowaternet for transitional, coastal and marine waters has been implemented in 2002 with the purpose of acquiring fresh, targeted and reliable data. Eurowaternet technical guidelines set out the data content and format required by the European Environmental Agency from maritime conventions and national sources [11].

The activities within the framework of Coastal monitoring and management – COAST Project focus on activities in further development and derivation of advanced environmental indicators for monitoring and evaluating European coastal and marine eutrophication, including the improvement of algorithms for processing of satellite data and adaptation and application of numerical models for the provision of physical and biological data required for indicator calculation [12].

5 Integrated Indicators and their Applicability

Besides the necessity to develop indicators in the theme eutrophication and hazardous substances, the information on biological quality of the environment and effect of various substances (multistress) on the quality of environment caused by human activity is required. It is therefore necessary to develop integrated indicators of impact.

Current intensity of work on indicators leads to discussion about the danger of excessive amount of data, so we agree with the opinion that sets of indicators should aggregate the data contained in a variety of single environmental indicators. Namely, too many indicators may only compromise the legibility of information and therefore the indicators should focus upon interaction and not the environment itself. Opponents of such an attitude hold that due to a series of assumptions that must be made in a process of aggregation, the original datum gets lost. Little has been done to date on integration of indicators [13].

6 The Problem of Karst Area

There is exceptionally high probability of obtaining irrelevant data in karst areas. When accompanied by incautiousness those may erroneously interpret the state of an aquifer.

The problems of monitoring water in majority of karst terrains may be classified in 4 categories [14]:

1. Where to monitor for pollutants: At springs, cave streams, and wells shown by tracing to include drainage from a facility to be monitored or at wells selected because of convenient downgradient location, whereby it is sometimes necessary to perform monitoring several kilometres away from the facility.
2. Where to monitor for background water quality: At springs, cave streams, and wells in which the waters are geochemically similar to those to be monitored for pollutants but which are shown by tracing not to include drainage from the facility.
3. When to monitor: Before, during, and after storms or meltwater events and also at known base-flow conditions - rather than regularly with weekly, monthly, quarterly, semi-annual, or annual frequency.
4. How to reliably and economically determine the answers to problems 1, 2, and 3: Reliable monitoring of ground water in karst terrains can be done, but it is not cheap or easy.

7 State of Indicator Development in the Republic of Croatia

7.1. *The Obligation to Develop Indicators*

As is the case in a number of other countries, especially those in transition, Croatia also suffers from the lack of basic data concerning the environment and the information about the data already in existence, as well as the lack of quality statistical data, particularly the qualitative and quantitative data on interaction of development activities and state of the environment – the indicators, as basis for the process of (political) decision-making.

Particular emphasis should be placed upon obligations resulting from the activities related to EEA and the activities derived from various conventions as well as those related to ensuring public access to information, based on Aarhus Convention [15].

Environmental protection in the Republic of Croatia has for years been the task of various administrative and professional institutions. There are series of data concerning the state of the sea, air, water and soil. Major problem arises from the fact that such data are not mutually correlated, they are sometimes partial, often mutually incompatible, and has until recently been hardly accessible to participants and the general public.

Environmental Protection Act [16] adopted in 1994 in its Article 41 provides for the obligation of the former State Nature and Environmental Protection Directorate to institute environmental information system in collaboration with the ministries and other state administrative bodies: obligations of the institutions which should participate in building such a system are governed by Regulation concerning the environmental information system [17] laying down the content, methodological basis for environmental information system, obligations, method of delivering data and the method of administering the environmental data.

Implementation of the Register of emissions in the environment in the Republic of Croatia [18] has started in 1997 with only few subjects reporting the pollution. A significant rise in the number of reported polluters has been recorded during subsequent years [19].

There is a lack of correlation between environmental data and socio-economic development or, more precisely, there are no indicators. For example the data related to surface waters are collected and their administering is financed by Croatian Waters (Hrvatske vode) or other state institutions that is companies, but they are not clearly identified at national level nor compared with the existing EU indicators [20]. The data on wastewaters and their treatment are procured from competent offices, that is companies who manage sewerage systems and devices for wastewater treatment as well as from industrial establishments who use and pollute water and discharge wastewaters. The data referring to private systems for several households are not collected at all as those are outside the scope of responsibility of municipal utility companies. Finally, in statistical processing of environmental protection it is necessary to involve to greater extent the households as units of natural consumption and pollution of water.

7.2. *Dispersion and insufficiency in processing the indicators of coastal environment in the Republic of Croatia*

Collection, storing and usage of data and information concerning the sea, in connection with indicators of pressure, state and impact on the environment and humans is not satisfactory. There is no common national programme which would cover in an integral manner the measuring and analysis of the state of the sea in Croatia nor all the types (DPSIR) and kinds of indicators. For that reason there is no unique data bank, but on the contrary [20]:

- Data on the state of quality of the sea, sediment and biota are mainly found in the Institute for Oceanography and Fisheries Split-Dubrovnik and Ruđer Bošković Institute Rovinj-Zagreb.
- Data related to pressures from urban infrastructure systems and water resources in Croatian Waters.
- Data related to pressures from faecal pollution of beaches in the Institute of Public Health.
- Data related to socio-economic pressures in coastal zone in State Bureau of Statistics.

Pressures/impacts on eutrophication or total influx of nitrogen and phosphorus into the sea have never been estimated on an integral basis. There are neither measurements of atmospheric sedimentation nor measurements of loads which by surface flow from coastal terrains – watersheds reach the sea. There is no document or report presenting data on the quantity of nutrients discharged annually into the sea from single source or all the sources nor has an effort been undertaken in defining the methodology to calculate such values with regard to particular karst features of coastal belt and the islands in Croatia.

The data concerning intensity of construction in littoral are not accessible although they may be readily obtained using satellite or air views. Nobody has by now collected such data nor is there an appropriate study assessing the magnitude of such an indicator.

There are no indicators for heavy metals as their concentration is not measured with water flow.

Data on concentration of metals in seawater, sediment and in selected bioindicator organisms do exist within the institutions that perform such measurement. There is no integral report and state evaluation nor the trend of change for the entire Adriatic.

There are no data concerning pollution by oil and oil products, but one may find the data on marine accidents and in that sense possibly assessed quantities of oil and oil products discharged into the sea. Damages are recorded by surveyors of the Ministry of environmental protection and by Port authorities so that the data concerning possible figures may be obtained from those bodies.

Data on the intensity of annual faecal pollution load discharged into the coastal sea in tons per year do not exist. The reason therefor is that the wastewaters flow of is not measured so that the load may not be estimated on the basis of directly measured data.

In Croatia to date, the data have to major extent not been gathered or processed in compliance with the method of reporting in the EU, apart from some which are mainly linked to the state of seawater quality. That means that without further processing of available raw data one may not obtain the necessary information adapted to the method of reporting in EU documents. That refers in particular to indicators of pressure which are particularly missing, that is, they have not till now been evaluated systematically and integrally.

The major shortcoming of the data related to features of wastewaters from communities, industry and watercourses, that is the sources of pollution is that no measurement of flow is performed with the measurement of concentration of particular indicators. Therefore all the data measured are useful only as indicators of relative state and may not be used in calculation of pressures nor for assessment of nature of waters pursuant to Croatian legislation.

The Environmental Agency which was established by virtue of Decision of the Government of the Republic of Croatia [21] as central institution for gathering and aggregating the environmental data on national level, data processing, administering environmental database, monitoring the state of the environment and environmental reporting aims to institute indicators listed in the Table 1. Values of some are being reported on the Agency web page [23]. Special Croatian indicator is envisaged for karst protection [24].

Table 1. Draft list of national indicators for the sea [22].

Item	Indicator
1	Classification of coastal sea
2	State of eutrophication
3	Biological seawater quality
4	Sources of inflow of nutrients into the sea
5	Pollution of the sea by hazardous substances
6	Phytoplankton algae in transitional and coastal waters
7	Concentration of chlorophyll-a in transitional, coastal and marine waters
8	Oxygen regime in coastal waters and the sea
9	Accidental discharge of oil into the sea
10	Beach water quality
11	Introduction and spread of "imported" species
12	Protected coastal zone
13	International cooperation in sea-related management

8 Reporting on Coastal Area at Local Community Level – Example of the Primorje – Gorski Kotar County

In the Environmental state report of the Littoral-Mountain County [25], major sources of water and sea pollution have been indicated in table form although they refer to industrial polluters only. Furthermore total wastewater quantity in m^3/year is presented, while the section dealing with characteristics of technological wastewaters merely enumerates hazardous substances registered in wastewater.

In the section dealing with quality of coastal water it is stated that in the area of Croatian littoral a systematic testing of sanitary quality of coastal seawater is carried out as well as the series of occasional surveys for specific purposes such as establishing environmental state of the sea for the purpose of determining optimum location of underwater discharges, establishing receptive capacity of the sea within bays and locating the nautical and tourist facilities.

It also states that the Land-based pollution monitoring programme – LBA, in implementation since 1994, makes part of systematic programmes related to the sea, but not within the meaning of seawater quality, but for monitoring the introduction of pollution from land into the sea.

The report furthermore refers to Internet pages of the Institute of Public Health which by different colours indicates the presently valid assessment of seawater quality as high-quality, suitable for bathing, moderately polluted and more heavily polluted on the basis of [26]:

- Internal criteria for purity of seawater for bathing introduced on the basis of proper experience and opinion in order to single out in assessing the areas with seawater that is very clean and not only suitable for bathing.
- Regulation concerning the standards on beach seawater quality [27] prescribing more stringent criteria than the corresponding European directive [28] as guideline values laid down in European directive are adopted as binding in our Regulation.

- criteria of World Health Organization and Environmental Programme of the United Nations.

In 2005 the national Environmental Agency published their first report on the sea, coastal zone, fisheries and aquaculture [29] which is based on marine environmental indicators. Data, principally on the state is, where available, reported for individual counties.

9 Conclusion

The review of international and regional indicators brings to evidence the existence of a series of indicators which endeavour to present the state of littoral area and the sea for the sake of decision-making, policy making and informing the public.

Croatia is distinguished by substantial quantity of data obtained for the sake of internal monitoring of state from the part of competent institutions, scientific research and participation in international projects, but such dispersed and non-aggregated data are not presented in the form of indicators, simple or integrated, which would be easily comprehensible and accessible to development decision-makers and the public.

On the basis of global and regional experience in Croatia, a system of sustainable development indicators for coastal zones and the sea must be introduced which shall suit the capabilities and particular features of our country with respect to karst characteristics of our coast and the islands in which the process of pollution takes a course which differs from that in other parts of the region. Croatia indicators must at the same time be more stringent, but also specific and compliant with those of international community in order to present the state on the territory of our country and integrate themselves into indicators for the Mediterranean which must also be further developed.

Establishing of the Environmental Agency whose task is creation of common environmental information system in the most expedient and most economical way and the introduction of quality and representative indicators accessible to the public represents a breakthrough that will significantly improve the methods of reporting used to date, such as description of methods and presenting evaluation in text form without an insight into historical patterns.

In the field of local community one must mention to activity of Littoral-Mountain County which by elaborating its report on the state of environment identified the existence and lack of particular data essential for the environment, and represents the first step in creating environmental metabase.

On the basis of aforesaid and owing to particular position of the Adriatic as closed sea within the closed Mediterranean sea it is necessary to apply all the international and regional standards, reinforced by domestic standards which should in the sector of land-based pollution and pollution from ships become even more stringent. In that respect the development of separate indicators in areas having exceptional landscape value and of sustainable development indicators in the areas of tourist infrastructure development is proposed, especially the indicators of interaction of port and transhipment facilities with resources of certain specific industries such as tourism for which state of the environment is of the prerequisites for its very operation.

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USING ENTROPY FOR QUANTIFYING SUSTAINABILITY IN AGRICULTURAL SYSTEMS : A CASE STUDY IN TOROGH RESEARCH STATION

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In this paper a method for quantifying sustainability of agro-ecosystems, based on over-production of entropy, is suggested. It is demonstrated that how land management practices could change the excess of entropy in an agro-ecosystem. Different crops have different value of over-production of entropy. It is assumed that these differences are due to a varying, but in many cases an excessive, use of high artificial energy and characteristics of the crop by itself plays a minor role. While the method allows only for rough estimate of entropy in agro-ecosystems, it can be stated that, due to a reduction of artificial energy input, sustainability could be improved. Also the results of barley and sugar beet confirm this matter. Nevertheless, all the examined crops are far from reaching a sustainable state from a thermodynamic point of view.

1. Introduction

The terms "sustainable" and "sustainability" have been variously defined and widely used, but there is general agreement that it has an ecological basis. In the most general sense, sustainability is a version of the concept of sustained yield, the condition of being able to harvest biomass from a system in perpetuity because the ability of the system to renew itself or be renewed is not compromised [10].

For agro-ecological, research to contribute to making agriculture more sustainable, it must establish a framework for measuring and quantifying sustainability [8, 15]. Farmers need to be able to assess a particular system to determine how far from sustainability it is, which of its aspects are least sustainable, exactly how it can be changed to move it toward sustainable functioning. And once a system is designed with the intent of being sustainable, farmers need to be able to monitor it to determine if sustainable functioning has been achieved. The methodological tools for accomplishing this task can be borrowed from the science of ecology [10]. Ecology has a well-developed set of methodologies for the quantification of ecosystem characteristics such as nutrient cycling, energy flow, population dynamic, species interactions and habitat modification [1]. Using these tools, agro-ecosystem characteristics, and how they are impacted by humans, can be studied from a level as specific as that of an individual species to a level as broad as that of the global environment. On approach is to analyze specific agro-ecosystems to quantify at what level a particular ecological parameter or set of parameters must be at for sustainable function to occur. A few researchers have already done work in this area, and some of quantifiable ecological parameters that were used for quantification of sustainability are: soil organic matter content [9], input : harvest loss ratio for each macronutrient [13], biocide use index[1] [13], ecosystem biophysical capital[2] [7], soil enzyme activity [5], peak standing crop [21] and plant species diversity [21].

Another kind of approach is to begin with the whole system. Some researchers, for example, have been working on developing methods for determining the probability of an agro-ecosystem being sustainable over the long-term [6, 11]. Using a systems framework for measuring the carrying capacity of a particular landscape, they apply a methodology for integrating the rates of change of a range of parameters of sustainability and determine how quickly change is taking place toward or away from a specific goal. Such an analysis is limited by the difficulty of choosing which parameters to integrate into the model, but has the potential for becoming a tool allowing us to predict if a system will be able to continue indefinitely or not. The paucity of this kind of data indicates that much research of this kind still needs to be done.

But entropy (as an indicator of degradation) could be used as an index for quantifying of sustainability in agro-ecosystems. A system, which accumulates entropy, can not exist for a long time and will inevitably be self destroyed. In this assay thermodynamic approach suggested by Svirezhev [22] and by Svirezhev and Svirejeva-Hopkins [23] was used for estimation of the entropy balance of agro-ecosystems.

2. Materials and methods

In accordance with second law of thermodynamic the entire input convert to output with defined efficiency. Nowadays, industrial cultural energy is used either directly or indirectly in agriculture. Direct use occurs when industrial cultural energy is used to power tractors and transport vehicles, run processing machinery and irrigation pumps, and heat and cool greenhouses. Industrial energy use occurs when industrial cultural energy is used off the farm to produce the machinery, vehicles, chemical inputs and other goods and services that are then employed in the farming operation.

Pimentel supposed that the relation between the crop yield, y, and the input of the artificial energy, W, is linear, $y = \eta W$. The empirical coefficients of energy efficiency (η) were calculated from different agro-ecosystems in many countries and various regions. In fact, the coefficient η is a modification of the well-known thermodynamic efficiency coeficient, which is a consequence of the first law. On the basis of first law of thermodynamic this coefficient is usually less than 1, however, on the contrary, the coefficient, η is may be more than 1 in agro-ecosystems. The point is that formally we

[1]- Index based on several factors, including use rates, toxicity and area sprayed; values above 50 are considered indicative of excessive biocide use.

[2]-Defined as the capture of adequate solar energy to sustain cycles of matter in an ecosystem.

must take into account the solar energy (E_s). Thus the correct form for the efficiency coefficient will be, $y = \eta\ (W + E_s)$ or $\eta = y / (W + E_s)$.

In the case of Pimentel's coefficient η we get $y = f\ (W + E_s)$, It is obvious that when industrial energy input equal to 0, this mean that W=0,

$$y(W, E_s) \approx y\ (0, E_s) + (\partial y / \partial W)_0\ W. \tag{1}$$

Here we assume that the first term is negligibly small in comparison to the second one. If the artificial energy input trends to 0, then any cultural plant will be replaced by wild vegetation. As a result the crop yield will be very low if W is small.

$(\partial y\ /\ \partial W)_0$ term is η, which relatively constant for current crop at a given climate. Therefore, the intensification of agriculture (the increase of crop production) correlates with an increase of artificial energy flow in the ecosystem. There are however limits, determined by the second law, which prevent an infinite increase of crop production. In other words, we pay for the cost of increasing productivity by degradation of environment, in particular, soil degradation [22, 23]. In order to support these statements, the entropy balance for an agro-ecosystem to be considered as an open system in thermodynamic sense was calculated. In the open systems the total variations of entropy result from of two items:

$$dS_{(t)} = \sigma = d_iS_{(t)} + d_eS_{(t)}. \tag{2}$$

Where $d_iS_{(t)} = dQ_{(t)} / T_{(t)}$, $dQ_{(t)}$ is the heat production caused by irreversible processes within the system and $T_{(t)}$ is the environmental temperature (in K) at a given point of the earth's surface, which is occupied by an agro-ecosystem. The term $d_eS_{(t)}$ corresponds to the entropy of exchange processes between the system and its environment, i.e. the entropy export out of the system. In accordance with the theory, developed by Svirzhev [22] the annual total rate of entropy is equal to:

$$\sigma = 1 / T\ (W + \lambda P_1 - P_0). \tag{3}$$

Where T is the mean temperature of a vegetative period and the value W is the annual inflow of artificial energy. If the value λP_1 is a part of the annual gross agro-ecosystem production, P_1, which remains on the field (respiration and residues), then $d_iS = (W + \lambda P_1) / T$. Additionally $d_eS = - P_0 / T$, where P_0 is the annual gross primary production (GPP) of a successionally closed ecosystem.

It is obvious that the net production is equal to $(1\text{-}r)P_1$, where r is the mean respiration coefficient. The term rP_1 then describes the respiration losses. The k_{th} fraction of the net production is being extracted from the system with the yield, so that the crop yield equals to:

$$y = k\ (1 - r)P_1. \tag{4}$$

The residues are equal to $(1 - k)(1 - r)P_1$. Then:

$$\lambda P_1 = (1 - k)(1 - r)\ P_{1\ residue} + rP_{1\ respiration} = (1 - k + kr)\ P_1. \tag{5}$$

Using Eq. (4) we express the value P_1 by the known value of crop, *y*, and re-write Eq. (5) in the form $\lambda P1= (1 - k + k_r)P_1 = ((1 - S) / S)\, y$, where:

$$S = k\,(1 - r). \tag{6}$$

And finally, the entropy balance of agro-ecosystems will be:

$$\sigma = \frac{1}{T}(W + \frac{1-S}{S}y - P_o). \tag{7}$$

Net primary production (NPP) one ecosystem at our research where supposed 2500 kg ha^{-1} (personal communication with natural research organization, 2004), since, the annual GPP was used 35 GJ ha-1 (Table 5). When using the Pimentel relation $y = \eta W$, then:

$$\begin{aligned}\sigma &= \frac{1}{T}[W(1-\eta+\frac{\eta}{S}) - P_o] \\ &= \frac{1}{T}[y(\frac{1}{\eta}+\frac{1}{S}-1) - P_o]\end{aligned} \; . \tag{8}$$

It is obvious that if $\sigma > 0$, then a system accumulates entropy. Using the part of Eq. (8) containing only *W*, we get from the condition $\sigma = 0$ an estimation for "limit energy load":

$$W_{cr} = \frac{P_o}{1 - \eta + (\eta / s)} \; . \tag{9}$$

It is obvious that if $W > W_{er}$, then $\sigma > 0$ and such an agro-ecosystem destroy its environment, i.e. an agro-ecosystem cease to be sustainable. Note the "limit energy load" concept is a typical empirical one and it refers to the maximum value of the total anthropogenic impact (including tillage, fertilization, irrigation, grain transportation and drying, etc.) on one area unit of agricultural land.

Using the part of Eq. (8) containing only y under the same condition "sustainable crop", i.e. the maximum crop production (in dry matter) for "sustainable agriculture" was calculated:

$$y_{cr} = \frac{P_o}{(1/s) + (1/\eta) - 1"} \; , \tag{10}$$

where y_{er} means sustainable crop.

2.1. *Site experiment description*

The data for the case study were collected at the agricultural Torogh research station of Ferdowsi University of Mashhad (36° 38′ N and 59° 7′ E), Iran Long term (> 30 years) mean annual rainfall in Mashhad is 282 mm and with a mean annual temperature of 12.7° C (mean minimum 0.3° C in January; mean maximum 24.6° C in June). Soil of experimental site with 29.7 percent sand, 53.7 percent silt and 16.8 percent clay is placed in loam silty class.

2.2. *Measurement of cultural energy inputs and harvest outputs*

In order to Measurement of cultural energy inputs and harvest outputs, the total output and input that took place on the agricultural Torogh research station within 2003 year was recorded, all calculation was adjusted according to available statistic. Input included machinery, pesticides, fuel, seed and fertilizer. This included the kind of input as well as the amount and date of application. The inputs were measured in kg per ha. To account for the energetic loud of each component conversion factors are needed. For this we used the method of Pimentel [19] with the modification of Trümpler [24]. The total energy content (in Pimentel's sense) of different inputs is shown in Table 1. In order to estimate agro-ecosystem's outputs (crop yield) information about total energy content of harvested biomass, which comprises fruit and also a fraction of straw, was needed (Table 2). Furthermore data was needed concerning the gross production of the crops. This was calculated with straw/fruit and shoot/root ratios taken from the literature. Combined with the energetic information about fruit and straw the factor k was calculated (Table 2). Note that the unit, which the ratios refer to, is biomass. Since the energy content of fruits, straw and roots are different (see Table 2); these ratios were recalculated in energy units. Zarea-Fizabady [28] found that respiration coefficient for herbaceous plant communities growing in the study site to be 0.3. This value was used to estimate GPP on the basis of NPP.

3. Results and discussion

Results showed that inorganic fertilizer (30.8%) particularly nitrogen fertilizer, consist the most proportion of the energy input. Fossil fuel for equipment (26.5%), irrigation systems (24%) and energy invested in off the farm equipment (12.4%) are in the later step (Figure 1).

Growing level of energy inputs to agricultural have played an important role in increasing yield levels in many of the worlds agricultural ecosystems over the past several decades. However, using the modern industrial technology result in increasing entropy. In the other word high entropy in modern agricultural systems is the cost which human being pays for alternating ecological relationship with industrial inputs.

In the agricultural Torogh research station, 51.5 % of energy use is direct, and 48.5 % is indirect. The production of fertilizers special nitrogen fertilizer accounts for the great majority of indirect energy use in agriculture. Nearly one third of all the energy used in modern agriculture is consumed in the production of nitrogen fertilizer [14]. This energy cost is high because nitrogen fertilizer is used so intensively and because a large amount of energy is required to product it [19]. This energy input could be reduced greatly by using manure, biological nitrogen fixation and recycling.

Table 1. Energy content for relevant agriculture inputs.

Product	Energy content [MJ kg^{-1}]	Reference
Inorganic fertilizer		
N	80	Average values of different studies (Deleage [4];
P	14	Projektgemeinschaft Bioenergieträger [20])
K	9	
Organic fertilizer	3.2	Palz and Chartier [18]
Pesticides	77-254 [MJ l^{-1}]	Special values for all different pesticides (Pimentel [19]; Trümpler [24])
Seed	2.99-5.67	Special values for all different crops (Burmeister [2])
Machinery production	86.8	Bowers [3]
Transport	8.8	Loewer *et al*. [16]
Maintenance	47.7	Fluck [5]
Fuel	41[MJ l^{-1}]	Projektgemeinschaft Bioenergieträger [20]

Table 2. Gross energy content of different crops at an average water content of 20% (MJ kg^{-1}) [14].

	Fabaceae	Beet	Barley	Wheat	Grassland
Gross energy content of fruit	15.4	16.4	14.8	15.0	14.6
Gross energy content of straw	14.5	13.4	13.9	14.0	14

Table 3. Land management, input and output of energy in the agricultural Torogh research station (2003).

Crop	Cultivation area (ha)	Energy input W [GJ ha-1]	Energy output y [GJ ha-1]	η (output/input)
Wheat	20	35.24	126.00	3.57
Irrigated barley	30	31.17	98.05	3.14
Dryland barley	24	22.39	48.35	2.16
Forage corn	7	31.67	120.41	3.80
beet	2	126.58	196.00	1.55

Table 4. Straw/fruit- and shoot/root-ratios for different crops [12, 25, 26, 27]

	Fabaceae	Beet	Barley	Corn	Wheat	Grassland
Straw/seed ratio	2	0.3	1	0.7	0.9	-
Shoot/root ratio	7.5	0.8	2.8	4	2.9	3.3
k	0.78	0.93	0.73	0.72	0.74	0.70

Table 5. *k, S, T* and *r* values for different [21].

crop	*k*	*S*	*T* (in K)	*r*
Wheat	0.74	0.48	290	0.35
Barley	0.73	0.47	290	0.35
Corn	0.98	0.63	299	0.35
Beet	0.93	0.60	295	0.35

k = The fraction of the net production is being extracted from the system with the yield.
S = The fraction of the gross production is being extracted from the system with the yield.
T = Mean temperature of vegetation period (in K)
r = mean respiration coefficient.

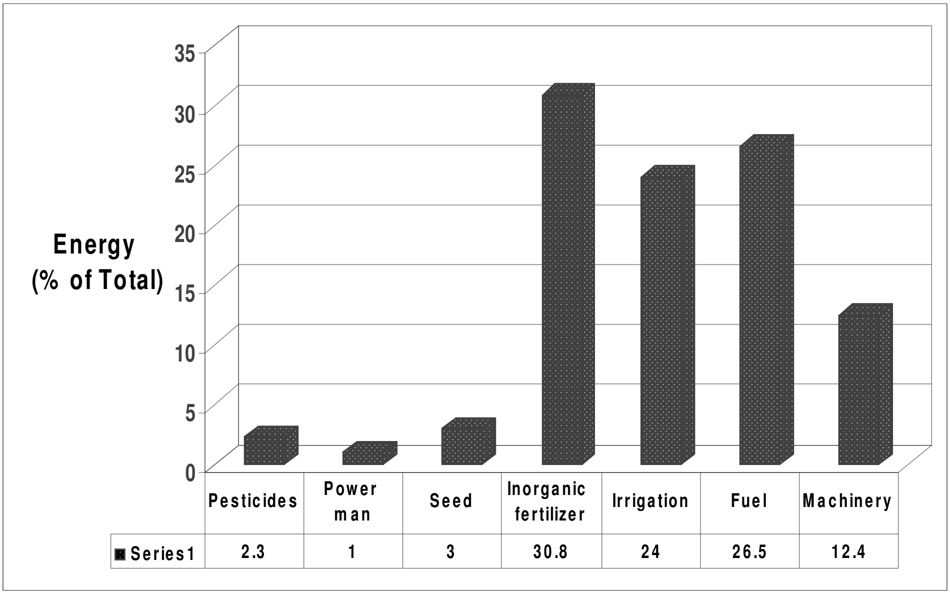

Figure 1. Composition of the total agricultural energy input in the Torogh research station in 2003 in percent.

50 percent of total direct energy is consumed in irrigation systems, this energy is high because world wide 65 percent of the water used in irrigation is wasted (evaporated or transpired), meaning that only about 35 percent of applied irrigation water actually contributed to crop growth [17].

Some wastage of water is inevitable, but a deal of waste could be eliminated if agriculture practices were oriented towards conservation of water than maximum of production. Another 26 percent of total the energy used in off the farm to produce the machinery and farm equipment.

To set an example the scheme of further calculations will be demonstrated for wheat. In order to calculate the entropy balance of a wheat field with Eq. (8). We have to know the values of W or y, η, $S = k\ (1 - r)$, P_0 and T. The energy input for wheat field in 2003 is equal to 35.26 GJ ha-1’ the output, which is the crop production y (grain + the main part of straw), is equal to 126 GJ ha-1 (see Table 3). Using these values the ratio η = output/input was calculated, η=35.24/126 ≈ 3.5.

From Table 5 we get K= 0.74, and since r=0.3, then $S= k\ (1\text{-}r)$ = 0.481. After Zarea-Fizabady P_0 is equal to 35 GJ ha-1 and the average temperature of air during vegetation period is 290 °K. Substituting all these values into Eq. (8) we get: Σ = 0.496 GJ ha-1 K^{-1} per year.

Using Eq. (9) and Eq. (10) the limit energy load and the sustainable crop production per year was calculated: W_{er} = 7.21 GJ ha-1, y_{er} = 25.75 GJ ha-1.

In order to estimate the deviation of the system from a sustainable trajectory we introduce the following criterion:

$$S_d = \frac{W - W_{cr}}{W_{cr}} = \frac{y - y_{cr}}{y_{cr}}. \tag{11}$$

Using Eq. (11) we can estimate the deviation from a sustainable agriculture for wheat in this year, $S_d \approx 0.79$. ,Also these calculations is done for other culture in 2003 year (see Table 6). The highest and less amounts of entropy was observed in sugar beet and barley, especially rainfed barley, respectively (Table 6).

Low excess of entropy in barley field especially dryland barley, which is very similar to a natural ecosystem, is expectable. Producing of entropy in agriculture is closely related to the level of modification of natural ecosystem processes. The costs are small when humans leave the basis structure of the ecosystem interact. But when a complex natural ecosystem is replaced by a crop monoculture with a life form very different from that of the native species producing of entropy rise steeply [22].

So, low entropy amount in rainfed barley is expected because of lower manipulating by human being.

Table 6. Entropy excess, σ, and deviation of sustainability, S_d, in 2003 for different crops in the agricultural Torogh research station.

crop	Entropy excess [GJ ha-1 K^{-1}]	W_{er} [GJ ha-1]	Energy input [GJ ha-1]	y_{er} [GJ ha-1]	Energy output [GJ ha-1]	S_d
Wheat	0.47	7.21	35.24	25.75	126.00	0.79
Irrigated barley	0.36	8.30	31.17	26.08	98.05	0.73
Dryland barley	0.14	10.90	21.39	23.54	48.35	0.49
Forage corn	0.45	6.58	31.68	25.00	120.41	0.79
beet	0.75	17.38	126.58	26.94	196.00	0.86

y_{er} = The sustainability crop production
W_{er} = The limit energy load

Substituting the term k (1-r) with S in Eq. (8), this Equation is re-written in the form:

$$\sigma = \frac{1}{T}[W + (\frac{1}{k(1-r)} - 1)y]. \quad (12)$$

In accordance with Eq. (12) some approach for designing sustainable system is:

1. *Firstly reduced anthropogenic energy input, W;* because of humans try to force on the environment in the production of food, energy is needed in order to maintain optimal growth and development of the crop organisms. Larger inputs of cultural energy enable higher productivity. However, there is not a one-to-one relationship between the two. When the cultural energy input is very high "return" on the "investment" of cultural energy input is often minimal [2, 10].
2. Sustainable agro-ecosystems enable through decrease input of industrial cultural energy and increase of biological cultural energy produce food with more energy efficiency. Biological cultural energy is renewable and in facilitating the production of harvestable biomass is efficient. Also, agro-ecosystems that rely mainly on biological cultural energy are able to obtain the most favorable ratios of energy output to input.
3. *Secondly reduced crop production, y,* but this of course would counteract the aims of agriculture. Moreover, this is not suitable measure, as is the case with intensively production of rice in southeast of Asia. Intensified biological systems, which have low entropy, can keep yield in high level [1].
4. *Thirdly, increase of export of biomass;* this corresponds to the increase of k in Eq. (11). For instance, by removing more straw with the harvest. But this could decrease the soil organic carbon in the long run, which has a negative effect on soil fertility and therefore can not be the aim of sustainable agriculture. Moreover, the process of extraction of residues (straw and roots) requires a lot of additional energy. Therefore, to increase k we must increase W. As a result, we do not only decrease σ, but it may also increase. As a conclusion, the reduction of anthropogenic energy input seems to be most useful strategy. The study in hand proves the effectiveness of this tool. On the one hand the waste of fertilizer was reduced and on the other hand the yield increased, which could, however, partly be a result of different weather conditions. As suggested in this paper, the key to more sustainable use of energy in agriculture lies in expanding the use of biological cultural energy. Biological input are not only renewable, they have the advantages of being, and able to contribute to the ecological soundness of agro-ecosystems.
5. The excess of entropy of a site depends on several parameters. In the following the accuracy of the applied data will be discussed. Primary productivity was calculated with accurate data about crop yield and empirical values for biomass ratio between root, straw and harvested parts of the plant. In addition, a general respiration coefficient was applied, which had been determined by Zarea-Fizabady [28] on several herbaceous species of the study site. As plant cannot adopt both the root/shoot ratio [25] and respiration coefficient [16, 28] to weather and soil conditions, these values only allow an estimation of the real situation.

6. The resulting excess of entropy significantly depends on the selected reference system. To accord with the hypothesis, the reference system must be a mature natural system, which is similar to the examined agro-ecosystem. Only in this case the anthropogenic ecosystem still has the same property to export entropy to its environment without degradation. Under the climate and soil conditions in Mashhad district a natural succession would result in a pasture ecosystem (like on all pasture in semiarid region of Iran). As a pasture is not successionally close to farmland, we selected long-term fallow pasture as a reference, which produce 2500-kg ha^{-1} biomass that seems to be a good compromise between the demands of maturity and similarity.

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ENERGY POLICY AND PLANNING

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LARGE-SCALE HEAT PUMPS IN SUSTAINABLE ENERGY SYSTEMS: SYSTEM AND PROJECT PERSPECTIVES

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In this paper, it is shown that in support of its ability to improve the overall economic cost-effectiveness and flexibility of the Danish energy system, the financially feasible integration of large-scale heat pumps with existing CHP units, is critically sensitive to the operational mode of the heat pump vis-à-vis the operational coefficient of performance (COP), which is set by the temperature level of the heat source. When using only ambient air as the heat source, the total heat production costs increases by about 10%, while the partial use of condensed flue gas from the CHP unit as a heat source results in an 8% cost reduction. Furthermore, the operational analysis shows that when a large-scale heat pump is integrated with an existing CHP unit, the projected spot market situation in Nord Pool towards 2025, which reflects a growing share of wind power and heat-bound power generation electricity, will reduce the operational hours of the CHP unit significantly, while increasing the operational hours of the heat pump unit. In result, a heat pump unit at half heat production capacity in combination with heat-only boiler represents as an alternative to CHP unit operation, rather than a supplement to CHP unit operation. While such revised operational strategy would have an impact on electricity markets, the result indicates that in a sustainable energy system, either a large-scale heat pump should fully replace an existing CHP producer, or the size of the heat pump to be integrated with an existing CHP unit should be much below half of the CHP unit's heat production capacity. The CHP with heap pump design should allow for both combined (CHP unit and heat pump) and sole operation (heat pump only).

1 Introduction

Large-scale integration of intermittent renewable energy technologies such as wind power and photovoltaics into existing energy systems represents a major opportunity for increasing energy efficiency, reducing emissions, and optimizing the economic feasibility of the energy system [1]. Such development will be requiring innovative solutions in the design and operation of the overall energy system, in particular in order to regulate in periods of excess power production, maintaining power quality, and increasing the capacity value of small power producers.

In the case of Denmark, with about 20% of the total electricity supply coming from wind power and plans for increasing the share of wind power to 25% by 2010, measures are being developed for securing a continued efficient and cost-effective integration of grid-connected wind power. Besides the large-scale penetration of wind power, the

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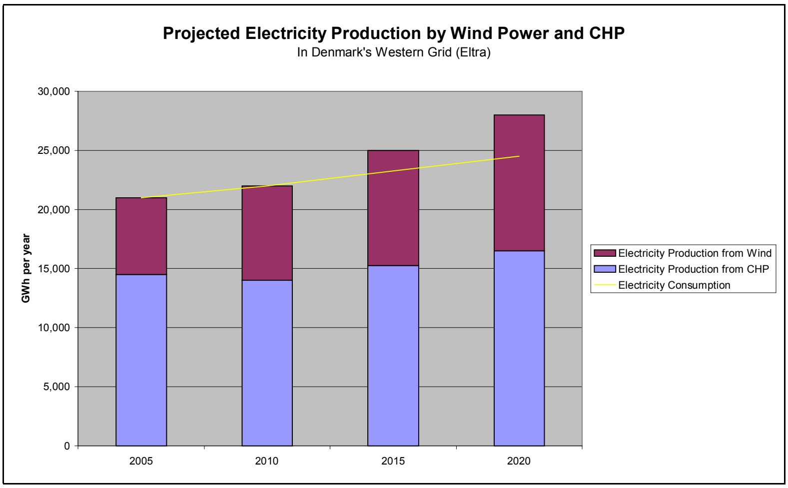
Danish energy system is furthermore characterized by a continued policy strategy to promote system energy efficiency in the form of distributed combined heat and power production, which supplies about 50 of total heating demand and 50% of total electricity demand in 2003.

In the Western part of the Danish electricity system, annual electricity production from wind and CHP is currently matching annual electricity demand, and new off-shore wind farms and the increasing demand for district heating, are giving rise to a situation in which supply surpasses demand, and periodically results in critical excess supply. Figure 1 illustrates the increasing significance of this challenge [2].



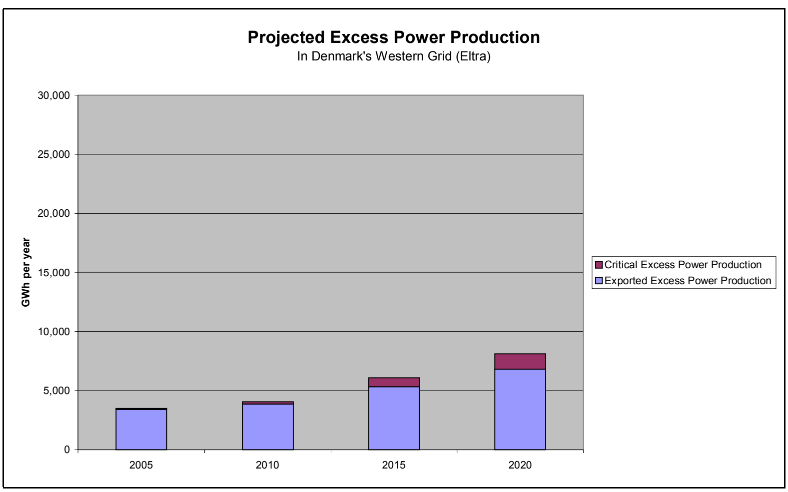


Figure 1. The current and projected share of wind power and CHP-based power generation in Denmark's Western grid, and the resulting projected excess power generation.

To avoid the foreseen problems in planning for extensive penetration of wind power in Denmark's Western grid, current plans suggests that new wind farms should better target export markets. Such strategy will involve major investments in increasing transmission capacities to neighboring countries Germany, Norway, and Sweden. Meanwhile other strategies, which attempts to assess opportunities for allowing an even larger share of intermittent renewables into the Danish energy system (50% or more of total annual electricity production) might be more cost effective [3]. Such alternative strategies seeks to increasing the flexibility of the existing supply and distribution network; strategies that may be more cost-effective, while neutralizing the problems related to critical excess production of electricity.

The strategy to limit excess electricity production by increasing the flexibility of the national system, involves the design of sustainable energy systems which relies on the integration of effective storage and relocation technologies. Figure 2 exemplifies the overall principle for the integration of selected storage and relocation technologies.

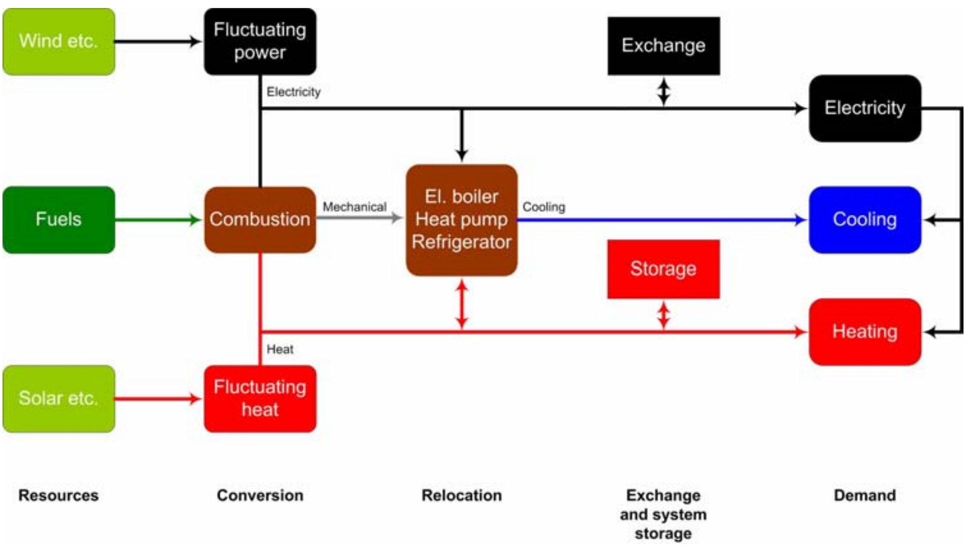


Figure 2. Integration of storage and relocation technologies in the energy system.

But which options are more feasible, from a technical, environmental, economic, and financial perspective? Heat pumps, hydrogen storage, or pumped storage? Comparative techno-economic analyses of advanced system designs are required in order to assess the comparative advantages and disadvantages, and possibly to identify those options which could benefit from particular attention by policy makers and project developers.

Lund *et. al* [3] points to one most promising option in a short- to medium-term perspective; integration of large-scale heat pumps at the site of existing CHP-plants. From extensive system analyses using the model EnergyPLAN it is found that the levelized economic benefit in the case of Western Denmark amounts to €2.5 mill. per year at current wind power production levels. The analysis shows that it will be feasible to integrate a total of 350 MWe heat pumps, equivalent to the installation of one 1 MWe heat pump at the site of the average CHP-plant.

In fact, standard large scale compressor heat pumps are typically available up to about 1 MWe, equivalent to 3-6 MW heat output, though the integration of heat pumps is likely to be requiring a customized design process in most cases [4,5]. Issues related to ozone-depleting and global warming contributing refrigerants is a problem of the past as CFC and HCFC are being phased out, introducing natural working fluids like carbon dioxide and water. Findings suggest that natural working fluids are introduced without compromising the COP, however it is known that using carbon dioxide as a working fluid in compression systems generate high pressure differences across the compressor as well as large efficiency losses associated with the throttling process [6]. The Danish Technological Institute is currently collaborating with the Centre for Positive Displacement Compressor Technology to design and demonstrate a technology that balances the rotor forces in twin screw compressors for high pressure applications, thereby significantly improving the efficiency of large-scale heat pumps using carbon dioxide as the working fluid.

A strategy intended to promote the integration of heat pumps suggests the emergence of a new role for small power producers in the regulation of supply and demand for electricity. Certain key conditions needs to be taken into account for this purpose; most importantly the communication between the system authority and the individual plant operator and the ability of the plant to react quickly to supply requirements. Research projects indicate that starting and stopping plants currently may take from as little as 10 minutes to as much as 4-6 hours. Furthermore, the ability and willingness of the small power producer to supply reactive power would increase the flexibility of the system and allow the system authority to postpone certain investments in for example condensators [7].

However, in order to establishing such new regime and role for small power producers, regulators will be required to establish new conditions for grid-connection under which investment and operational strategies will be reflecting the economic costs and benefits.

In fact, in March 2005, 26 Danish CHP plants offered their combined capacity of 361 MWe to the Western grid authority, thereby suggesting a model for how it may become financially attractive for small power producers to become providers of regulative capacity [8]. Taking it a step further, small power producers may just as well also provide an additional regulative option by allowing the central grid authority to bid for making use of heat pumps at the site of the CHP plants for the purpose of taking excess power production in situations of such.

2 Objective and methodology

In this paper, it is assessed whether the suggested economic feasibility of system integrated large-scale heat pumps is currently reflected in the market place, i.e. whether it is financially attractive under the current market conditions for small power producers to install and operate a large-scale heat pump.

The analyses are making use of a design and optimization model of a typical CHP-plant with and without heat pump, on the basis of which a financial cost-benefit analysis is prepared. The energyPRO software [9,10] is used to model and optimize the simulated operation of the plant over the planning period. On the basis of the financially optimized plant operation, a simple net present value approach is used as the key criteria for assessing the comparative financial feasibility of the options included under the analysis.

3 Techno-economic assumptions

In the comparative analysis of the performance of large-scale heat pumps, 3 options are compared:

Reference: Continued operation of an existing 4 MWe (3 MWe + 1 MWe) natural-gas fired CHP plant with 1,200 m3 thermal storage (grid-connected, heat used for district heating).

Alternative A: Reference plus cold source heat pump (ambient air is always used as heat source).

Alternative B: Reference plus partial hot source heat pump (flue gas is condensed and periodically used as heat source).

All options are optimized according to an operational strategy that allows demand at any given hour to be met by the cheapest production component, shifting between or combining the engine-generator, the heat pump, and the heat-only boiler, producing to the thermal storage, whenever feasible.

3.1 *General assumptions*

With 2005 as the first full year of operation, the case options are analyzed over a planning period of 20 years, equivalent to the assumed life time of the heat pump, furthermore assuming that to be the remaining lifetime of the existing CHP unit; making all investments fully depreciated within the planning period.

A nominal financial discount rate of 15% p.a. is applied in the calculation of the financial net present value. While this discount rate may seem rather high, it is assumed to mirror well the time preference for new investments among the stakeholders in focus. Current fiscal premiums and taxes are assumed constant in nominal terms. Fixed and variable O&M costs are assumed to increase at the rate of inflation, which is assumed to be 2% p.a. A 70/30 debt-equity ratio is assumed, debt being financed over 10 years at 5% p.a. effective. The results and conclusions are not particular sensitive to these assumptions.

Table 1. Key techno-economic assumptions.

	Reference	Alternative A	Alternative B
Heating demand			
Annual supply	24.5 MWh		
Installed capacities			
CHP-Heating	6.5 MW	3 MW	4 MW
CHP-Electricity	4.0 MWe		
Efficiencies			
CHP unit – thermal	39%		
CHP unit – overall	90%		
Heat-only boiler – overall	95%		
Heat pump – COP		3	4
Investments			
Heat pump		0.7 mill. €	0.9 mill. €
Var. annual O&M costs			
CHP unit (€/MWh elec. prod.)	6.5 €/MWh		
Heat-only boiler (€/MWh heat prod.)	1.5 €/MWh		
Heat pump (€/MWh heat prod.)		4.0 €/MWh	4.0 €/MWh

Financial fuel costs and revenues from the sale of electricity are based on previous year values (March 2004 to February 2005) projected to develop over the planning period at rates similar to those projected for economic costs according to the Danish Energy Authority [11]. The initial natural gas price is based on fixed monthly prices for large consumers [12], and the electricity selling and purchase tariff is based on Nord Pool spot market prices [13]. Electricity purchase taxes for heating purposes apply for electricity used to feed the heat pump.

3.2 *Case options*

Table 1 holds the key techno-economic assumptions for the 3 options under analysis. Particular uncertainty relates to the coefficient of performance (COP) of the heat pump, which is highly sensitive to the temperature levels of the heat source as well as of the heat sink. The average temperature level of the heat source is uncertain due to the various conditions under which the heat pump will operate: in periods the engine-generator will not operate and the heat pump will have to operate on the basis of a low temperature heat source, perhaps ambient air, under which conditions the COP may be as low as 2, and is unlikely to reach a COP higher than 4 (Alternative A). In other periods the heat pump may operate in parallel with the engine-generator, possibly allowing for heat recovery by condensation of flue gasses, which will result in a relatively small temperature lift of the heat pump, as a result of which a COP of between 3 and 5 may be achieved (Alternative B). By including these two alternatives in the comparison, the aspect of this uncertainty is partially explored.

The specific investment cost for large-scale heat pumps is not expected to change towards 2030; however the COP for new heat pumps may be expected to improve by as much as 20% by 2030 without any increases in investment and O&M costs (ref). The potential increase is not considered under this analysis. The technical life time of the heat pump is assumed to be 20 years at the specified O&M costing levels.

4 Results

Figure 3, 4 and 5 illustrates the operational characteristics of the 3 case options during a week in November 2005. It appears from a review of this and other weeks over the planning period that following the integration, the heat pump will significantly overtake heat production from the CHP unit, Alternative B more so than Alternative A.

Table 2 shows the key financial results for the operation of the 3 case options. It appears that the financial conclusion as to which option is the more feasible depends on the operational mode of the heat pump. Alternative A, which uses ambient air as the only heat source increases total costs of operation, while Alternative B, which is assumed periodically to be using condensed flue gases as heat source, reduces total costs of operation.

Table 2. Key financial results.

	Reference	Alternative A	Alternative B
Net present value (€)	-6.3 mill.	-7.0 mill.	-5.7 mill.
Levelized production cost (€/MWh-heat)	41.1	45.7	37.7

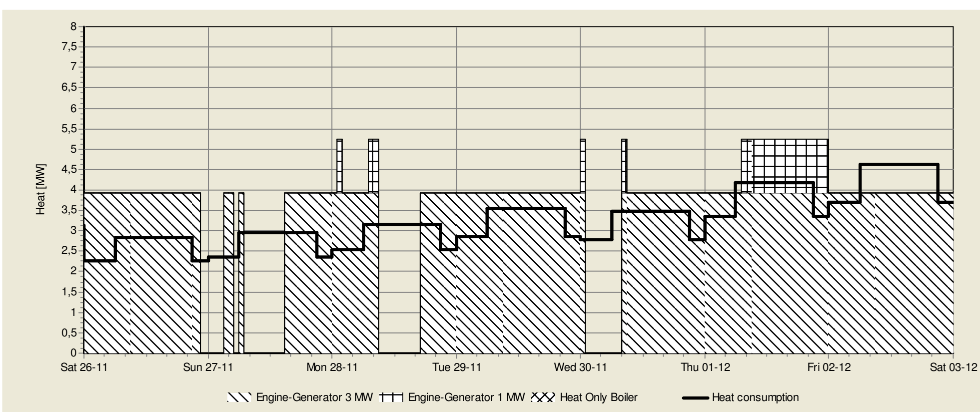


Figure 3. Sample operation profile for optimized natural gas fired CHP plant without heat pump.

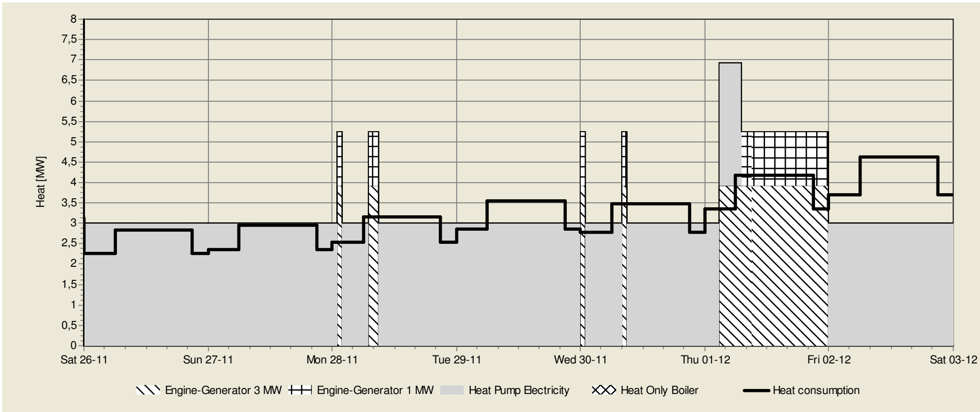


Figure 4. Sample operation profile for optimized natural gas fired CHP plant with Alternative A heat pump. Heat pump overtakes a significant share of heat production.

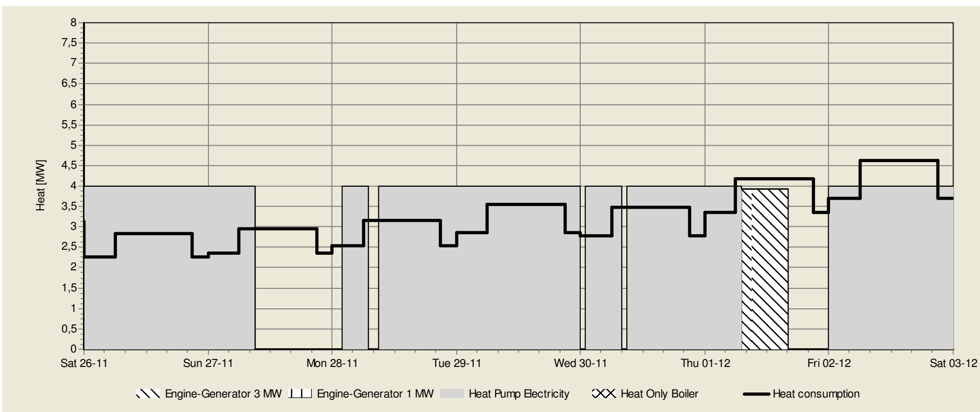


Figure 5. Sample operation profile for optimized natural gas fired CHP plant with Alternative B heat pump. Heat pump overtakes almost entirely heat production.

5 Conclusion

In conclusion, the results indicate that when a large-scale heat pump is integrated with an existing CGP plant, the current and projected spot market situation in Nord Pool supports a significant preference in the operation of the heat pump over the CHP unit. However, uncertainties related to the performance of the heat pump under various operational strategies must be further explored through tests and demonstration projects.

On the financial feasibility, the results indicate that when using only ambient air as the heat source (Alternative A), the overall heat production costs increases by about 10%. In an operational situation that allows a COP increase by 25% accompanied by an almost 30% increase in investment costs (Alternative B), the overall heat production costs are reduced by about 8%.

The financial results are obviously sensitive to the conditions for grid-connecting small power producers. The recent move by small power producers teaming up to supply firm capacity to the grid may benefit the CHP unit relatively if rewarded. Another potential impact will be the combination of the increase in electricity demand due to the use of heat pumps and the decrease in electricity produced by the CHP unit, which will drive up market prices for electricity and thereby benefit the CHP unit relatively over the heat pump. Analyses will be required in order to assess the feed-back effect on the Nord Pool spot market from the possible increase in demand from heat pumps and the reduced electricity production from the CHP units.

Possibly, financial instruments are required effectively to improve the financial viability of large-scale heat pumps. Most importantly, it seems relevant to discuss which options the market may reasonably introduce in order to introduce the option for regulating electricity demand and supply by the use of heat pumps in order to avoid critical excess power production and exports of excess power production, whenever feasible. Also of current interest, will be the effects of introducing CO2-credits and RE-certificates.

With construction periods of less than 1 year, the integration of large-scale heat pumps with existing small power producers may be the key to allowing a large share of intermittent renewables into the power grid in the short to medium-term. Such integration would help to securing a flexible and cost-effective operation of the energy system and policy strategies and market conditions should be developed accordingly.

However, while such revised operational strategy, based on a design that allowes for both combined (CHP unit and heat pump) and sole operation (heat pump only), whould have an impact on electricity markets, the results indicate that in a sustainable energy system as the evolving Danish energy system, either a large-scale heat pump should fully replace an existing CHP producer, or the size of the heat pump to be integrated with an existing CHP unit should be much below half of the CHP unit's heat production capacity.

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CDM IN AFRICA - AN ANALYTICAL FRAMEWORK FOR ACTION *

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The implementation of CDM, as a market-based tool for sustainable development, is seen as a critical tool for the African continent to achieve the Millennium Goals. Many years, initiatives and projects have been implemented since the start of Kyoto´s negotiations, but few have been the achievements in terms of the impacts in regional sustainable development. This paper carries out a survey on the most recent CDM programmes and initiatives conducted in African countries (especially in the Sub-Saharan Countries, as they are perceived to suffer the greatest impacts of climate change). This survey was then used to analyse and identify particular trends, especially when focusing in the achievements of those programmes and initiatives. A panel was also set-up for comparing past and present scenarios. Based on the information collected and analysed, a strategy was put forward to overcome the main weakness and propose possible steps for future action.

1 Introduction

Climate change is no longer a new topic in the international agenda. The key issue lies on the general perception of public and private actors; some see it as a threat, others as an opportunity, others still as business driver, while a few may actually perceive it as new path for sustainable development (SD),. When climate change was first discussed in a global forum [1], probably no one anticipated such a long and drawn-out process on this matters (i.e. that it would take so many years for its ratification), and above all, most did

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not envisage the current state of affairs, namely the insufficient steps being taken and the lack of political leadership demonstrated by the many of the institutions involved in the process.

Furthermore, the Clean Development Mechanism (CDM), a forward-looking, market-based tool for engaging poor countries in carbon abatement initiatives, was looked upon to become one of the main drivers of SD in several of the less developed countries (LDCs), but, at present (and now more than 10 years later), this is yet to become a reality. This paper will, therefore, explore this issue in more detail, focusing on one of the regions expected to benefit the most from CDM initiatives, the African Continent.

This paper is not only based on a survey of literature, publications and web-based material, but also on two years of field experience in connection to the development of the Project "CDM for Sustainable Africa - Capacity Building for Clean Development Mechanism in Sub-Saharan African Countries". The objective of this project was to create an appropriate framework for CDM project implementation and facilitate CDM - related investments in the SAHEL (meaning the Sahara desert boundary) and the SADC (Southern Africa) regions [a].

2 CDM as A Development Tool

Starting from the premise that combating climate change is a global endeavour, it was agreed that action would have to be concerted at the international level; and from this concept the idea of optimising emissions reductions in the most cost-effective way naturally followed. The concept of developing projects that could reduce Green House Gases (GHG) emissions anywhere in the world (possibly, where these were cheapest) emerged from this framework, such that these credits could then be used in covering carbon emissions in other countries, especially those subject to emissions ceilings. As said in Article 12, paragraph 2 of the Kyoto Protocol:

"The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3…"[1]

This makes sense in a global business approach. But there are always pertinent issues such as costs, available funds, risks, other more attractive projects, different commitments, the respect for sovereignty, addressing the environmental aspects as well as the global sustainable development objectives. Thus, a political and regulatory framework needed to be established. It was against this scenario of different perspectives and diverging goals that the foundations for CDM were established, at the first Conference of the Parties (COP).

Although CDM initial ideas were quite clear, as time went by, it has been perceived as not been able to achieve its initially proposed targets, for example, the Small Scale CDM Projects were to be an important tool in addressing the sustainable development of

[a] http://www.rgesd-sustcomm.org/CDM_AFRICA/CDM_AFRICA.htm
[1] www.unfccc.int

small communities, but those projects lack the critical mass to support the burden of the fixed costs. The second wave of more promising projects involved the transfer of appropriate technology to LDCs, but these often become constrained by the difficulty of demonstrating their additionality. In poor countries with a severe technology gap, the CDM Projects were expected to be a major push factor for sustainability in the industrial sectors, however, government bureaucracy and the absence of a support structure made such projects more difficult to implement [2].

Taking all of this into consideration, it is easy to conclude that CDM was not the expected magic pill for tackling climate change. This article will attempt to further develop and analyse some of the barriers that block CDM investments / actions and, wherever possible, shed some light on ways to overcome them, with regard to the African Continent.

As a final word, the authors would like to warn, that the growing feeling that CDM, as a market-based tool is failing to achieve the promotion of its sustainable development goals, makes it even more important to secure the benefits from carbon finance beyond its purely monetary benefits, otherwise, there is a risk of political repercussions and the re-evaluation of positions/attitudes by several donor organizations, as already alerted by the WWF [3].

3 African Situation

Africa is indeed not a big contributor of GHG emissions, as it only accounts for 3.2% of world emissions (1992 levels), mainly produced in the energy and land use sectors (32% and 37 % respectively), as can be seen in Figure 1. Although, this may in itself reduce any interest in this market for CDM projects, Africa is one of the most vulnerable continents to the potential impacts of climate change. Furthermore, the low industrial base poses a threat that economic growth, if a sustainable path is not chosen (i.e. less energy intensive and with cleaner technology process), will lead to the exponential growth in carbon emissions [4].

To accomplish this overarching objective, the proposed project takes the Kyoto Protocol agenda as a general framework for implementing its specific objectives, in other words, making proper use of the CDM to achieve sustainable development in Africa. This continent has an enormous natural resource potential, including energy resources, but also the world's lowest economic and social indicators, thus facing major development challenges at all levels.

The actions carried in the past within these countries had the intention of contributing towards the creation of the greatest number of CDM activities, the identification of barriers for investments, supporting actions for creating endogenous capacity to remove such barriers, and to avoid or minimise future emissions by promoting environment-friendly technology transfer.

On the surface, CDM has been regarded (by various players in developed and developing countries) as a cooperative instrument to promote sustainable development while achieving cost effective GHG mitigation. However, due to dissimilar economic, political, social and technological conditions in developing countries, Africa has not been able to attract sufficient investments through the CDM route. Of a total of 50 "Activities Implemented Jointly" (AIJ), projects during the pilot phase, only two projects came to

Africa. Recently, under the Netherlands Carbon Purchase Programme (CERUPT), out of a total of 20 projects approved, none has been approved for implementation in Africa. Furthermore, out of over forty business methodologies submitted to the CDM Board of Executives, of which eleven have been approved and six have gone as PDDs (project Design Document) to the CDM Executive Board (EB), only one on landfill from South Africa is under active consideration as the methodology is being approved (Source: http://www.cdmwatch.org/).

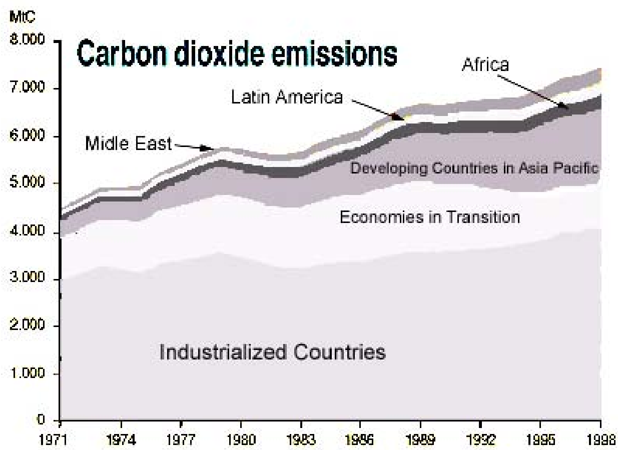

Figure 1. Carbon Dioxide Emissions per continent [4].

4 Past Activities

Here are some of the past activities on CDM in African Countries, more specifically in the area of capacity building and project portfolio building. The bellow list of actions does not try to cover all experiences in the continent, but instead to provide a general picture of the activities developed and the main outcomes achieved.

The Clean Development Mechanism and Africa. Regional Workshop. Accra, Ghana, 21 – 24 September, 1998 [5]. Main issues discussed:

- CDM Governance – Need for reduced bureaucracy and ensuring that the developments goals of the hosting country are actually achieved. The International Board composition should be of 11 members, out of which 6 from developing countries.
- African Focal Points – no agreement on whether Africa should begin to establish CDM agencies. Was suggested a partition of credits, 50% developed country partner, 20 host country partner, 20 % host country government, 4 % adaptation funds and 1 % for the CDM agency.

- Baselines – It was clear that the lack of precise and reliable data makes it difficult to build baselines. A combination of national (and or regional) and project-specific baseline would be required for CDM projects in Africa.
- Additionality – Due Africa's low level of emissions, additionality would be focused in financial aspects, so CDM would improve attractiveness of projects to investors.
- Monitoring, verification and Certification –SD objectives are to be incorporated in the process as an issue for further discussions to move from more short-term objectives (i.e. infrastructure or job creation), to "poverty alleviation". Capacity Building Programmes should target the lack of competence to carry out such.
- Equity issues –Africa, as has been marginalised in international mechanisms in the past, a quota system should be put in place to ensure enough CDM projects in Africa. Another aspect is that it should not be constrained with emissions targets.
- Getting started – A fund should be set-up to assist the development of credible projects and build confidence and overall understanding. This would support countries to develop agencies; adaptation strategies; project portfolios; capacity building, R&D and Demonstration programs.
- Other existing mechanisms – CDM must not be used as a substitute for other mechanisms such as ODA and GEF
- Types of CDM projects – energy and sustainable transport projects are to be pursued.

UNIDO at the project "Engaging the Private Sector in Clean Development Mechanism Project Activities", a United Nations inter-agency project, focused on Brazil and South Africa. One of the main features was the promotion of CDM projects by developing an Investment and Technology Promotion Office (ITPOs). The program followed an agenda of meetings between CDM Delegate Programme for South Africa and potential investors in Japan (around 30 between 21st to 31st May, 2003, in Tokyo).

The project was related as success, with "bridge-building" effects between Japanese investors and South Africa CDM Project Developers, and the presentation of a CDM portfolio of 23 projects. Many questions were raised concerning the institutional infrastructure, regulations, status of the Designated National Authority (DNA). The low share of energy related projects indicated that more capacity-building work needed to be done in this area. Many of the contact reports had parts of it made confidential as requested by the participants.

CD4CDM Project (on going at the present date, www.cd4cdm.org). United Nations Environment Programme (UNEP) launched the project "Capacity Development for the Clean Development Mechanism" with financial support from the Dutch Government. The UNEP Risø Centre (URC) is the supporting organisation contracted by UNEP to implement the project.

The project has the target to establish GHG emission reduction projects, consistent with national SD goals (especially in the energy sector), and also to prepare people in the host countries to became capable of analysing the technical and financial merits of projects and negotiating financing agreements with Annex 1 countries or investors.

The project aims at a broad understanding of the opportunities offered by the CDM, and developing the necessary institutional and human capacities to allow them to formulate and implement projects under the CDM framework. 12 countries, in 4 developing regions, have been selected to participate in the project: North Africa and Middle East; Asia; Latin America and Sub-Saharan Africa - Côte d'Ivoire, Mozambique and Uganda. The project has successfully implemented a series of 20 national and regional workshops and 4 books.

BEA International – Bureau of Environmental Analysis International, three-day workshop on Application of Climate Change and Energy Technologies: Opportunities and Incentives for Investments in Africa [6].

In this event, CDM related issues were discussed such as: regional capacity enhancement, public and private CDM initiatives, enhancement of partnerships between national and international private and public entities, country CDM programmes, and capacity building constraints (e.g. technical, information, institutional and financial capacity). Some of the main considerations were:

- On public-private partnership on CDM, it was recommended a common strategy to be developed in Africa.
- Capacity Building – general concerns were expressed regarding the skills and expertise of environmental ministries and environmental officers and trainers. Was a consensus that more training activities are needed to enable more CDM investments
- CDM awareness - international NGOs, regional offices, and CDM focal points must increase their efforts to persuade the international community to invest in African countries. Was also suggested the creation of a 'CDM Desk for Africa' or 'Regional Desks' to serve as advisory bodies.
- Small Scale – these should receive special attention in building the CDM portfolio, highlighting the community benefits.

Another special issue concerned small-scale projects. In creating a CDM portfolio, more attention should be given to the specific community benefit of a project. Other key issues discussed:

- The need to address the development criteria at country level (instead of adopting universal principles) and the risk of a 'race to the bottom'
- In the past, Africa's position against the sink projects was in line with European NGO's but now there has been a clear shift in this issue. As such, there is a lack of unity in the G77+ China Block and Africa's voice is not being heard.
- Africa need to gain experience in implementing CDM projects. There has been work in some baseline methodologies in the LULUCF at local level (Kenya), but yet some institutional problems exist to sort-out contractual arrangements

CDM for Sustainable Africa - Capacity Building for Clean Development Mechanism in Sub-Saharan African Countries. Project coordinated by the RGESD – IST, where, during 18 months a Consortium with European and African Institutions took forward the objective of creating an appropriate framework for CDM project implementation and facilitate CDM related investments in the SAHEL (meaning the Sahara desert boundary) and the SADC (Southern Africa) regions. To accomplish this goal, the project foster the understanding of CDM as a tool to achieve SD in Africa.

The "*CDM for Sustainable Africa*" project was therefore conceived to ensure attainment of long-term sustainable development of environmentally friendly technologies through capacity building. Feasibility studies for the most promising projects identified were developed for exploring these potential projects in the Sub-Saharan Countries, as well as a table of potential CDM Projects for the target region.

5 Current Situation

CDM is not a "common-sense" business and there are several barriers to its fulfillment as a development tool and also as a business oriented activity. Worldwide, there are many barriers and milestones within the CDM process, and all of them vary from project to project and from site to site. Thus, one must be proactive to overcome them according to each reality. Listed below are a few key points on the process that all participants must consider when pursuing a CDM application [7]:

- The role of the key entities established to manage and monitor the CDM;
- Legal process involved in developing and registering the project and sales of CER;
- The legal requirements in the Hosting Country, i.e. eligibility and 'additionality' test;
- Complying with domestic law frameworks, particularly legal ownership of CER, foreign investment restrictions, property law and security law issues;
- Project Finance and the various means of structuring and financing CDM projects and how the CER are transferred in the international and domestic registry systems;
- How the project management team plans deal with the risks particular to CDM projects and how to incorporate them into the negotiation of the CER; and
- The contracts, and compliance to the different perspectives that the project developer in a developing country may hold on various clauses compared to the CER buyer.

The main risks remains in the lack of reliable information and the need of a secure environment to promote the changes that must take place during the CDM life cycle (for the enterprise as well as for others stakeholders). At the end, this is what CDM is made of, changing towards a new framework for developing and securing their long term activities.

Within the "*CDM for Sustainable Africa*" project, an assessment was made to analyse the present barriers to CDM projects in the target countries. It consisted on a specific survey questionnaire with the leading questions/indicators related to policy, technical, financial and legal issues.

This material was used within the local stakeholders in Botswana, Mozambique, South Africa and Zambia and at Agrhmet Centre (that further administered those questionnaires in their Sahelian member states namely Niger, Cape Verde and Gambia). The list of barriers identified was:

- **Policy Barriers**: limited awareness of CDM in Government, NGOs and Private Sector; impromptus response by governments to ratify the Kyoto Protocol; no fully established CDM National Authority; lack of a formally functional SD criteria and dedicated committee; limited awareness of benefits of CDM and its relationship to business by Government, NGOs and Private Sector and limited fora at which CDM issues are discussed.
- **Technology Barriers**: limited awareness on renewable and energy efficiency tech. as potential CDM; limited and sometimes non-existence of knowledge on selection of appropriate renewable energy and energy efficiency technologies as potential CDM projects; very few countries have experience with developing CDM projects; limited, and in some cases lack of assistance to the private sector by Government and NGOs in resolving barriers; limited, and/or non-existence, of databases with information related to CDM; limited, and at times non-existence, R&D facilities for development and demonstration of CDM related technologies; limited human resource for the PDD elaboration and for new methodologies; few support services for PIN (Project Idea Note) and PDD elaboration and conducting feasibility studies, and formulation of business plans related to CDM and problems faced by countries with projects under development would include lack of: capacity to develop project, prompt government support, project development assistance (funding), skilled human resources to develop the PDD, finance to fund CDM work and men power to be allocated for CDM work.
- **Financial Barriers**: lack of financial base from local investors to contribute for project implementation, as there is limited to no awareness of local/regional institutions in CDM projects; limited awareness of availability of international investment sources and limited awareness of risks associated with CDM project implementation and of the transaction costs in CDM implementation and CERs selling on project economics.
- **Legal Barriers**: limited to no awareness of the Protocol as an international law within NGOs and Private Sector, as well as the legal issues in the development of CDM projects at all levels (Government, NGO and Privates Sector); limited, and for private sector almost no, awareness of Legal arrangements during CDM development and lack of capacity in most countries to negotiate for a CERPA.

6 Discussion

Looking to the list of barriers found, and also keeping in mind the conclusions and achievements of the last actions mentioned, there are some obvious trends, namely the following:

1. The lists of barriers continue to be more or less the same, despite the efforts of the international community;
2. CDM is seen much more as a form of gaining access to international funds than to build a Sustainable Development Agenda;
3. Private sector still lacks understanding of Kyoto related business opportunities;

4. The CDM initiatives are more common among governments, then academia and almost absent in the private and banking sectors.

Other issue frequently debated is the strong link between CDM projects and sustainable development, and how those investments are to be important for the local communities. However, with no clearly defined SD criteria (which are at the core of CDM project design), this issue of great importance, has so far received little attention by the main key players (as it was not to be expected).

CDM in Africa is mainly considered a source of foreign income, while other aspects are being disregarded. The numbers, on the other hand, show that Africa is losing this battle. The statistics reveal that Foreign Direct Investment (FDI), in the developing countries are concentrated in more or less 10 countries, with Africa's share of this capital decreasing over time, from around 17% in 1960 to about 3% by 1999. The whole continent (except South Africa) received only 0.6% of the world's FDI in 2000, as can be seen on Table 1 [8].

Also, these investments are not equally spread in the African economy, as they tend to concentrate in the natural resource industries such as mining, oil, timber, coffee, tea, cocoa; sectors where competitive advantages outweigh the negative factors [9].

From a CDM perspective, when considering the investments directly related to the CDM in developing countries, Africa does not come at the top of the list of hosting countries. Furthermore, when this information is cross checked – i.e. FDI and CDM investments – it is evident that one does not follows the other, as demonstrated in [10].

Also, in this paper is stated that low income, agrarian economies with relatively poor infrastructure have limited scope for attracting FDI inflows, regardless of whether their policies are trade-friendly. This is in line with the declining shares in global FDI inflows of low income countries in sub-Saharan Africa, despite their liberalization of trade and investment regimes. FDI flows have remained very modest, compared with other regions, such as Asia and Latin America.

Table 1: Distribution of World FDI inflows, 1986-2000 (in %). Source: [8].

Region	1986 - 1990	1993 - 1998	1999 – 2000
Developed Countries	82.4	61.2	80.0
Developing Countries	17.5	35.3	17.9
Africa	1.8	1.8	0.8
Latin America & Caribbean	5.0	12.3	7.9
Asia & Pacific	10.6	21.2	9.2
Central & Eastern Europe	0.1	3.5	2.0
Least developed countries (LDCs)	0.4	0.6	0.4

With regard to potential projects, although Africa lags behind in the preparation, submission and implementation of CDM projects, various options are physically present throughout Africa for the development of PDD and a large number of potential projects have been identified, mostly Small Scale CDM projects. Some examples are:

5. Better use of wood resources (improved stoves and efficient charcoal making processes);
6. Efficiency improvement in Coal based thermo-electrical facilities (optimization of coal combustion process, via better process monitoring);

7. Energy efficiency project with technology transfer. Cases of revamp of industrial units with technology transfer (i.e. insertion of bio-digestion plants on present units. As the incorporation of 3 different technologies in a slaughter house in Botswana;
8. Energy efficiency improving project with business as usual technology. Appropriate for CDM projects focused in industrial units revamp with BAU technology (i.e. enhancing of cogeneration in sugar cane mill in Mozambique (one case studied);
9. Landfill gas-to-energy projects. These projects may be attractive to be developed as CDM projects in regions where suitable landfills are available, such as South Africa. Also, these projects rely on existing CDM background (with methodology already approved. This was also the first CDM project registered);
10. Wind Mills (but not at all sites); and
11. Biodiesel and solar energy projects – alternative and / or renewable energy projects to specific sites and situations.

The results of the case-studies have shown that there are feasible opportunities for CDM projects in different areas of Africa and that, due to its heterogeneity and diversity, it is difficult to speak in general terms about what type of CDM projects would be feasible, as these potential projects are strongly related to local conditions and site specificities (physical and structural conditions), and to each Country's reality. Nevertheless, some general observations on the feasibility of different types of projects can be made, in a sectoral approach, as there is some homogeneity in technological levels across the continent:

Meat Sector – countries with a relatively large meat production sector in Sub-Saharan Africa: South Africa (1.8 Mton), Nigeria (1.1 Mton), Kenya and Tanzania. Meat product exports mainly from Southern African countries (Namibia, South Africa, Botswana, Zimbabwe and Swaziland). In the mentioned countries, there may be options for development of CDM projects based on anaerobic digestion of meat processing wastes, similar to what has been examined for Botswana.

Use of Agricultural residues – the northern and central African countries do not have very large amounts of agricultural process residues, however in these countries it mainly concerns field residues that are often hard to collect. Furthermore, utilization of these residues may cause unwanted soil degradation. In countries where there is a large population pressure on wood resources however, collecting and briquetting these field resources may be an option. Examples of countries with high concentrations of agricultural field residues (wheat and barley straw) are Egypt (10.6 Mton), Tunisia (1.1 Mtons), Morocco (3.0 Mtons), Ethiopia (5.3 Mtons), South Africa (4.2 Mtons) and Algeria (3.6 Mtons). If this is machine-harvested and no real alternative use is available, it could be feasible to generate power from this resource.

Sugar Cane Mills Cogeneration – the enhanced use of sugar cane bagasse in cogeneration scheme is particularly attractive in Non-Tropical Southern Africa, and particularly the small country of Swaziland (some 6 Mton of bagasse is available in this region of which 1 Mton in Swaziland). And yet, if this is a common practice around the globe, the present technological situation in African mills create an opportunity to, using BAU technology, have an electric energy surplus that is not present in the baseline (as energy generation is not considered in the mills' strategic planning). At the same time, better use of forestry residues, namely wood residue based power generation could be further developed. Other main African areas where large amounts of bagasse are available in concentrated form are Mauritius (1.5 Mton) and Réunion Island (500 kton).

Most of the above mentioned ideas for CDM projects are based on the increased utilisation of renewable resources for energy production. Another category of potential CDM projects relates to efficiency improvements of existing supply chains, such as improved charcoal production in (Niger and Mozambique case study), as well as grid extension that is focused in displacing local energy generation based on diesel engines (Zambia case study).

Furthermore, the local profile of the African private sector at present is mainly made-up of micro, small and medium-scale enterprises that often operate in the informal economy and, as such, most trade and investment promotion institutions do not reach them and channels for financial intermediation are ill-adapted to their needs [11]. Those that do not have access to information nor funding lines to undergo CDM projects.

This key support is critical in drawing a CDM strategy, as would it be difficult for those enterprises to seek for the necessary resources (financial and technological) to go through the CDM project cycle, as well as for reaching the international markets. Also it is difficult to argue that such modest additional CDM financing is the needed final push to make a project commercially viable, but it is still conceivable that the CDM could help to overcome non-financial barriers to implementing some climate mitigation projects.

Another key issue is that the host countries need to adopt appropriate SD evaluation methodologies that are transparent to potential investors, especially concerning the important aspects of project evaluation. This ill-defined part of the cycle could be quickly addressed if the methodology for approaching the issue were subject to a regional consensus, such that the potential similarities and specific differences could be respected. In this sense, the authors do recognise the potential of the methodology described by [12], based in a two angle analysis:

First – Recognise that GHG emissions, and the human induced global warming, are determined by general development pathways and by specific climate mitigation policies. Thus lead us to start thinking of future options in a more holistic way, rather than just focusing on individual energy supply, technology demand or adaptation measures. The critical aspect is to place climate policy in the broader context of technological and socio-economic policy development, rather than just being one among the many items of those policies.

Second – Recognition of the linkages and potential synergies and trade-offs in each concrete policy option. As the options were inventoried, it became clear that they are focused in a certain issue within a specific sector. However, for a full economic appraisal it is necessary to take into account the indirect impacts on climate (including mitigation and adaptation), development targets and social goals. Policy options must not be guided by sector-specific results but, instead, encompass the full spectrum of potential impacts.

And even if each country does define a set of criteria (and many are possible), this has to be made with the contribution of local stakeholders. The lack of interaction between knowledgeable technology partners and organisations representing local stakeholders is also at the core of another serious problem: the significant probability that the project design is suboptimal. This was, for example, observed in the development of a bio-digestion project based on Methane recovery and substitution of fossil fuels with biogas from abattoir waste (Botswana). The local organisation initially proposed to bottle the produced biogas. After the discussions with the European partner, this proposal was developed into a more flexible range of technical solutions to better suit local stakeholders expectations. However, a number of project ideas suggested by the local partners were deemed impossible to be converted into tangible CO2-mitigating projects.

Local partnerships are essential in preparing CDM project proposals to the PIN and PDD level. However, it is commonly observed that some local consulting teams operating in the region typically lack the technical background and adequate capacity to seek new opportunities for CDM Projects and their development to PIN and PDD level. Through international exchange programmes, local consulting organisations may gain increased exposure to foreign solutions that might be appropriate at the local level. Meanwhile, it is recommended that local CDM organisations are assisted in build expertise by contacting external partners with sufficient technical expertise to develop more suitable projects (developing CDM projects to PIN or PDD level).

Host countries need to promote the inclusion of CDM aspects in the financial engineering of projects. As illustrated by some of the technical solutions proposed in this project, there is a need to further develop capacity for sound financial project engineering. Furthermore, the inclusion of CER sales in project finance can significantly increase the feasibility of CDM projects. For many typical CDM projects, however, the major share of the investment is typically provided by local stakeholders who often do not clearly understand how to incorporate into the project finance possible benefits and additional fixed costs associated with trading CER's and the CDM.

Although this project has contributed to increased awareness among local stakeholders through the workshops organised, additional actions are required to facilitate the adoption of projects that are only feasible through the sales of CER's.

As was shown in the CDM barriers assessment phase, the official support structure for CDM in the African hosting countries (Focal Point and/or DNA) is considered rather weak. Several countries have not even ratified the Kyoto Protocol, and information on the definition of local SD criteria is often lacking. There is a clear need to develop local partnerships to stimulate local on-site activities, which would speed up the process of CDM project preparation and develop confidence with outside investors.

Difficulties to obtain accurate information from local sites for these specific projects (case studies) were also experienced, as many of the final users of the proposed CDM projects were not directly involved in the design process and did not clearly understand what was expected from them.

7 Conclusions

Anyone reading the above comments may consider that the barriers for developing CDM projects are insurmountable. At the moment, Africa has significantly less experience in the adoption of CDM projects and is making slow progress along the learning curve. There are, however, great CDM opportunities in different sectors of society.

In the political sphere, African countries need to ratify the Kyoto Protocol and establish national DNA and/or focal points. In addition, opportunities need to be identified and developed for projects that, indeed, present a strategic advantage in incorporating the sales of CER's, not only because of financial gains but also through their positive impact on both climate change and local sustainable development.

One of the forms to proceed with this strategy is to combine creative thinking, local entrepreneurship and the promotion of linkages with technology suppliers and R&D organisations in Europe.

As such, one option is to foster the understanding that it is necessary to develop a new model for CDM capacity-building activities in Africa. This model must be closer to the private sector, focused on relevant technical assistance to the project developers (consulting and technology providers), and in partnership with the local financial institutions (project finance). Only after these actors become fully aware of Kyoto business (and related opportunities) can we proceed to further initiatives focused on the local governments.

These actions are to be developed in a cluster approach, gathering players based on their competence (by sector and area of expertise) instead of their geographical disposition. By doing so, it is expected that CDM projects become closer to the local realities, while also strengthening a more solid portfolio of business initiatives.

After this first phase has been completed, further actions should be focused on Small Scale Projects and the definition of Sustainable Development criteria. This last aspect is a key element in the process of engaging the government and public opinion in consolidating the final elements of the CDM chain.

This method would allow, firstly, the creation of a set of solid projects, gathered by business areas and/or sectors, capable of attracting foreign investment (one of the key development issues at present). Secondly, the building of a framework to attain the critical mass necessary to make the CDM process move forward in the African continent. The first stage would entail disengaging the action from governments and placing the emphasis on the private sector (not necessarily associated to geographical distribution). Once this local CDM agenda gains momentum, it would be conveyed onto the local stakeholders for the definition of SD priorities, and be realised in Small Scale CDM projects most appropriate to local conditions (using the methodology suggested in the text).

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STRATEGY OF POPULARIZING WOOD WINDOWS FOR ENERGY SAVING HOUSE: STANDARDIZATION AND DEVELOPMENT OF FIRE-PROOF WOOD IN JAPAN*

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The research of difference of window frames between Japan and Europe shows that aluminum sash windows with higher thermal transmittance are popular in Japan and wood casement windows with lower thermal transmittance are popular in Europe. Popularization of wood windows for energy saving from houses is treated as one of the practical and effective means to reduce carbon dioxide emission in the sectors of commercial and residence against global warming in the coming commitment period of Kyoto Protocol. Standardization by Japanese Industrial Standards (JIS) and development of fire-proof wood are discussed as strategies to popularize wood windows. The standards of wood windows in Europe seem to have been prepared with schedule for the commitment period of the Kyoto Protocol aggressively and strategically for sustainable development. Detail research of European Standards on wood windows reminds us the difference of climate and wood used for windows between Japan and Europe. According to the information, the research for standardization of wood windows in Japan has just started since 2004 with weather test. Fire-proof five-plywood made of Japanese cedar, whose each veneer is impregnated with incombustible chemicals, is developed. Fire test is made by cone calorimeter for four natural woods and the developed plywood. Although the natural woods cannot clear the conditions for even Class 3 fire-proof materials, the developed plywood clears conditions for Class 1 by Building Standards laws.

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1 Introduction

Japan must reduce emissions of greenhouse gasses by at least 6 per cent below 1990 levels in the commitment period 2008 to 2012 against the global warming, because the Kyoto Protocol was brought into valid in February 16th, 2005. In fact, the emissions of allocated carbon dioxide have gone up 12.3 per cent above 1990 levels until 2004 in Japan. Although the industrial sector, among 7 sectors of energy industries, industries, transportation, commercial, residence, industrial processes and waste, is the largest emission source and accounted for 42.3 per cent of total emissions at 1990, the sector has reduced the emission by 3.4 per cent until 2004. On the other hand, the increasing amount of emissions from three sectors of transportation, commercial and residence is 149 megatons and is almost equivalent to the total increment of 140 megatons [1]. We should promote to reduce emission of carbon dioxide in these three sectors strongly. There are mainly three means to reduce atmospheric carbon dioxide; (1) Reduction of carbon dioxide itself by the use of natural energies such as wind-power generation or photovoltaic generation, or by the energy saving. (2) Fixing of carbon from carbon dioxide by photosynthesis of forest. (3) Carbon dioxide capture and storage under ground or in ocean. Energy saving is one of the effective and practical means in the coming commitment period.

Increase of greenhouse gas emissions in the commercial and residential sectors mainly has been caused by the increase of energy consumption for air-conditioning. Energy dissipation from rooms to outside occurs through windows, ceilings, walls and floors. The amount of energy loss from aluminum frame window, which is most popular in Japan, is the largest among windows, ceilings, walls and floors. The use of windows with low thermal transmittance can be effective to reduce energy loss in the sectors of commercial and residential sectors. Wood window is a prospective candidate against the global warming because of its two advantages; (1) it is effective for energy saving because of the low thermal conductivity and (2) it keeps the fixed carbon for longer time because wood is carbohydrate which trees had been fixed from atmospheric carbon dioxide by photosynthesis. Unfortunately, almost window frames are aluminium sashes and wood window is not so popular in Japan. Popularization of wood windows is needed to promote energy saving from houses.

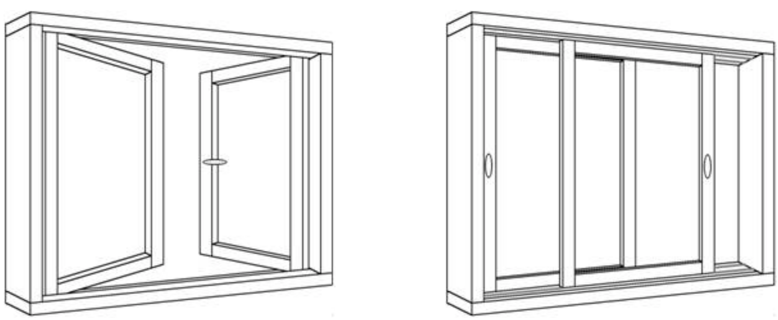
Standardization of wood windows is one of the effective means to popularize wood windows. Our institute has a standardization section of Japanese Industrial Standards (JIS). Our research group has handled standardization on a test method for wood windows since 2004, because only our group has treated wood as research themes until now in our institute. At first, we searched trendy of standardization on wood windows in Europe as advanced area of wood windows. In this paper, the trendy in Europe and the current situation in Japan are shown and compared. We will also show the orientation for standardization of wood windows as a result of comparison between Europe and Japan.

Improvement of wood demerits is another effective means to popularize wood windows. Wood has a demerit that it burns easily. In this paper, development of fire-proof wood is also treated. The developed fire-proof plywood is made of thinned Japanese cedar. Such use of thinned wood can keep Japanese artificial forest young and active with high ability of photosynthesis. The result of fire test will be shown.

2 Standardization of Wood Windows

2.1. *Japanese Windows*

There are two types of window frames; casement and sash as shown in Figure 1. The former opens and shuts by pivot or hinge and is popular in Europe. On the other hand, the latter opens and shuts by sliding and is popular in Japan. Such difference of window frame popularization between Europe and Japan comes of the differences of construction method and climate. Casement type has higher performances of airtight and heat insulating because it can be pressed to an outer frame strongly. It has advantage against severe winter in the north of Europe. Rooms in traditional Japanese houses are divided with paper sliding-doors called "shoji" or "fusuma", which can be removed easily from doorsills to make wide space and to let fresh air into the rooms. Such sliding-doors has advantage against muggy summer. Many recent rooms in Japan are westernized and have casement type doors. But many windows keep also traditional style of paper sliding-doors; sash frame.



(a) Casement (b) Sash

Figure 1. Window frame types.

Sash frame in Japan was made of wood in an early date. Wood has been replaced with aluminium because of easy maintainability since about 1975. Now aluminium frames account for 89 percent as shown in Figure 2. On the other hand, wood frames account for only 1 percent [2] and are mainly used in the northern part of Japan. Although the aluminium sash windows once had been popular in the northern part of Japan, many of them have been replaced with wood casement windows since about 1980. Because aluminium frame windows caused dew condensation and freeze in winter not letting them open. Such use of wood windows against dew condensation showed another advantage of energy saving for heating in winter in the northern part of Japan. Our strategy is to popularize wood casement windows in urban areas for saving energy used for air conditioning against muggy summer.

We thought that standardization of wood windows will help us to popularize them widely in Japan. We have already standards on windows as JIS A4706 [3]. Although it can be applied for even wood frame windows, it has been made for the request of Japan Sash Manufactures Association, which mainly treats aluminium sash windows. So we define the standard of wood windows apart from JIS A4706 as one of JIS for environment.

Figure 2 shows also shares of window frame materials in USA and Europe. For example, wood windows account for 95 percent in northern Europe of Finland, Norway and Sweden. The figure suggests that Europe is an advanced area of wood windows. We investigate the trend of standardization of wood windows in Europe for reference to make Japanese standards at first.

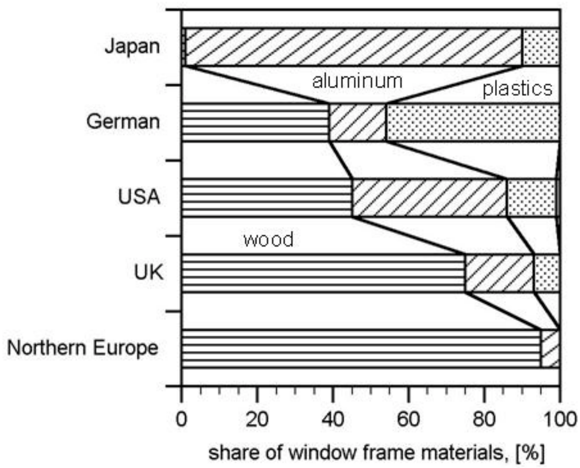


Figure 2. Comparison of materials for window frames among Japan, USA and Europe [2]

2.2. *Trend of Standardization of Wood Windows in Europe*

Europe has a long history of standardization of wood windows. For example, United Kingdom has a standard of BS644 on timber windows [4]. The original one was published at 1951. It was revised three times at 1958, 1989 and 2003. The current one was revised as a result of the withdrawal of British Standards which have been replaced by European Standards. It was also revised to make reference to enhanced security performance for timber windows as given in BS7950. The assurance of safety is helpful to popularize wood windows. The standard can be revised further more in the future, because European Committee for Standardization (CEN: Comite Europeen de

Normalisation) Technical Committee is currently preparing a series of European Standards for the testing and classification of windows, including timber windows.

In fact, the 29 countries in Europe belong to CEN at June 1, 2006. The 25 countries of them are European Union (EU) accession states, one is Romania which would be a next EU accession state and the other three countries are the Swiss Confederation, Norway and Republic of Iceland. Now the 29 countries in Europe have had the common standards of European Standards or they have reflected European Standards on their domestic standards. For example, Republic of Poland is one of new members of EU in 2004. The Polish committee for standardization was established in 1923. Although the committee has a long history on standardization, almost of work items by them was transposition of European standards before their accession to EU. The numbers of transposition of European standards to the total number of work items were 7816 to 8679 in 2002 and 4679 to 5196 in 2003 before accession to EU. On the other hand, Republic of Cyprus is also a new member of EU in 2004 but the Cyprus Organization for Promotion of Quality was just established in 2002. It seems CEN's strategy that many countries have common standards. It means that the European Standards can become International Standards easily with support of many countries.

Now we focus our attention to European standards on wood windows from viewpoint of energy saving. They published of standard of EN ISO 12567-1 whose title is "Thermal performance of windows and doors – Determination of thermal transmittance by hot box method – Part 1: Complete windows and doors" in 2000 [5]. They also published the similar standard only for frame as EN 12412-2 in 2003 [6]. Consequently, the standards of timber and wood-based materials for windows as EN 14220 and 14221 were published in 2004 [7, 8]. Such trend of European Standards suggests that they recognize wood frame for windows as prospective one for energy saving. We should realize that these standards were published in schedule to meet the commitment period of Kyoto Protocol by CEN in spite of the uncertain effect of Kyoto Protocol. It seems that Europe uses standardization effectively and aggressively for promotion of sustainable development.

2.3. *Standardization of Wood Windows in Japan*

Standardization of wood windows in Japan is very late in comparison with Europe. Only EN ISO 12567-1 among the mentioned standards was reflected on Japanese Industrial Standard of A4710 [9] in 2004, because the European Standard was also the International Standard. We think that the European Standards on wood-based materials for windows as EN 14220 and EN 14221 would be International Standards and then they would be reflected on JIS. We review those European Standards on wood-based materials for windows to find out problems which don't fit Japanese actual condition. There are two problems; (1) maximum moisture content is not greater than 18% for all elements and (2) minimum density of softwood and hardwood are 350kg/m^3 and 450kg/m^3, respectively. Generally, maximum moisture content of wood products is conditioned at 15% in Japan. The difference of maximum moisture content of wood between Japan and Europe is caused by the difference of climate. Almost Japanese artificial forests consist of soft woods of Japanese cedar and Japanese cypress. Some of those Japanese soft woods do not clear the condition that the minimum density is 350kg/m^3 in European Standards.

Our research group determined our orientation for standardization of wood windows with considering such problems found out in European Standards and the background that wood has replaced with alminium because of easy maintainability. We will do weathering test mainly, because the weather is very different not only between Europe and Japan but also between Pacific side and the Japan Sea side in Japan. We selected 7 locations for natural weathering test. Five kinds of wood will be tested; paulownia, Japanese cedar, Japanese cypress, Scots pine and white oak. The former three woods are peculiar ones in Japan or East Asia. We hope that those woods in Japan could be used as materials of wood windows. Eight kinds of paints will be tested. Accelerated weathering test will be executed for these samples. We will find out most appropriate paints that assure maintenance free for certain fixed period. These data can help us to represent Japanese condition when the International Standard of wood window will be made.

3 Development of Fire-Proof Wood

3.1. *Revision of Building Standard Law*

Land, Infrastructure and Transportation Ministry in Japan revised the Building Standard law on fire-proof materials for structural parts of buildings in 1998. The specification of fire-proof materials had been regulated until then; glasses and bricks could be used but wood could not. The new Building Standard law allows any materials with the performance stated in the law. The tests for fire-proof materials contain fire tests and hazard tests of combustion gasses. The required performance in fire tests is classified into three categories as shown in Table 1.

Table 1. Category of fire-proof materials and required performance in fire tests.

Category	Required time [min]	Performance
Class 1	20	1. Total heat released during the entire test is lower than 8 MJ/m^2 for the required time. 2. There are no hazardous clacks or holes which penetrate into the reverse side. 3. Maximum value of the heat release rate per area is lower than 200kW/m^2 for 10 and more consecutive seconds.
Class 2	10	
Class 3	5	

3.2. *Production of Sample of Fire-proof Plywood*

We tried to make fire-proof plywood. At first we impregnate incombustible chemicals into 3mm thickness veneer of Japanese cedar. The chemicals are borax compounds, which are developed and provided by Kohmix, Inc. Figure 3 shows the apparatus. There is a tank filled with incombustible chemicals in a sealed chamber. Some veneers are immersed into the tank. The pressure in the sealed chamber is controlled according to the procedure shown in Figure 4. Finally the veneers are took out from the chamber and dried.

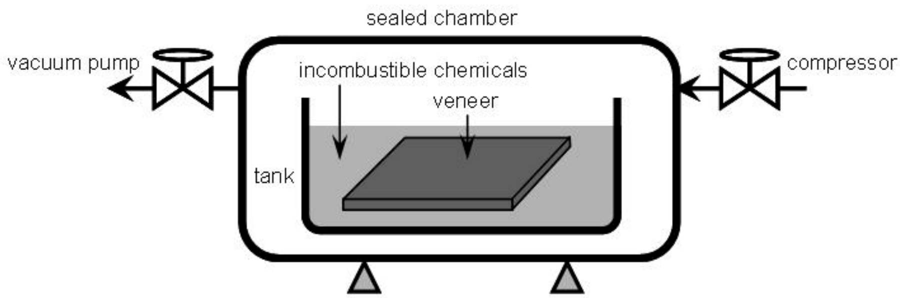


Figure 3. Schematic diagram of impregnating apparatus.

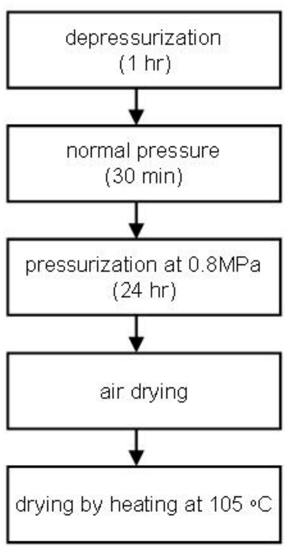


Figure 4. Schematic procedure of impregnating.

Five dried veneers are glued with incombustible adhesive, which is also developed and provided by Kohmix, Inc. It is pressed at room temperature with 0.7MPa for 20 minutes and then at 130 °C for 10 minutes. Finally we obtain 15mm thickness five-plywood as shown in Figure 5. The plywood is cut into 100mm x 100mm for the fire test by cone calorimeter.

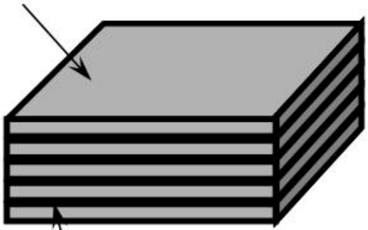


Figure 5. Fire-proof plywood.

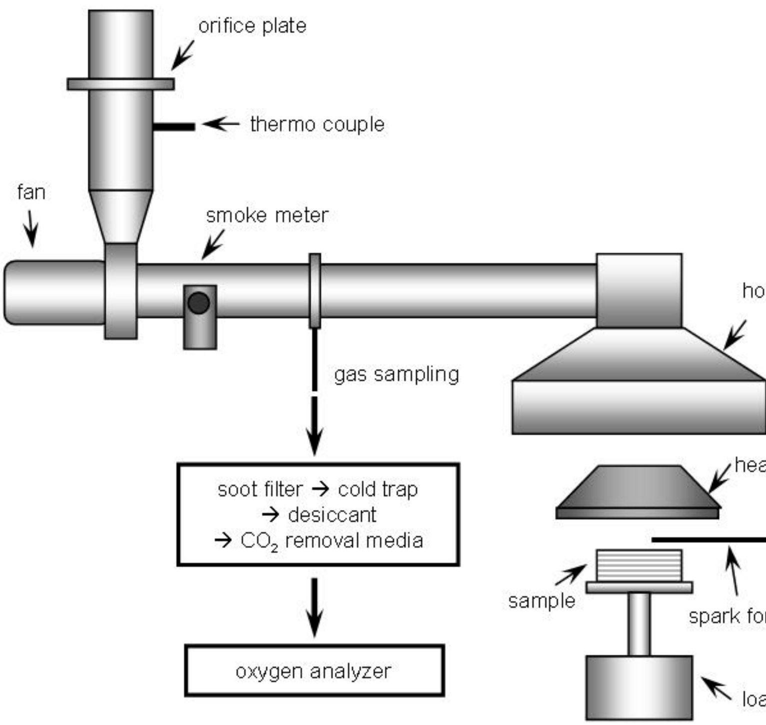


Figure 6. Apparatus of cone calorimeter for fire test.

3.3. *Fire Test*

Fire test is executed for samples and natural woods with cone calorimeter whose test method is defined in ISO 5660-1 [10]. Figure 6 shows the apparatus of cone calorimeter.

The sample is heated by cone shape heater. The combustion gas is leaded to hood. Soot, moisture and carbon dioxide are removed from the gas. The remaining oxygen is analyzed. The heat release rate and total heat release are obtained according to the theories by Thomton [11], Hugget [12] and Parker [13]. We can also obtain mass and smoke temperature. Figure 7 shows an example data obtained by this apparatus for natural Japanese cypress.

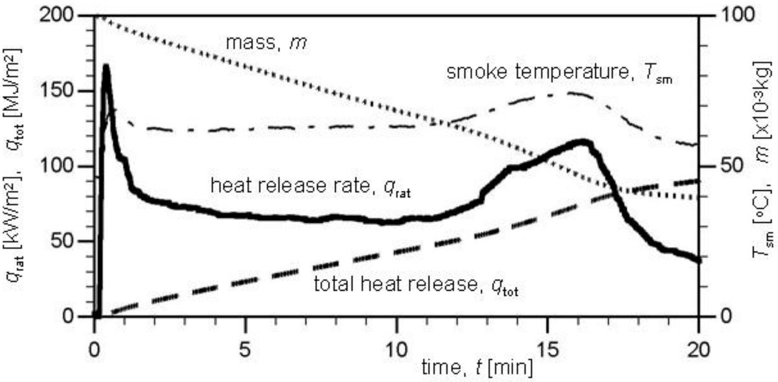
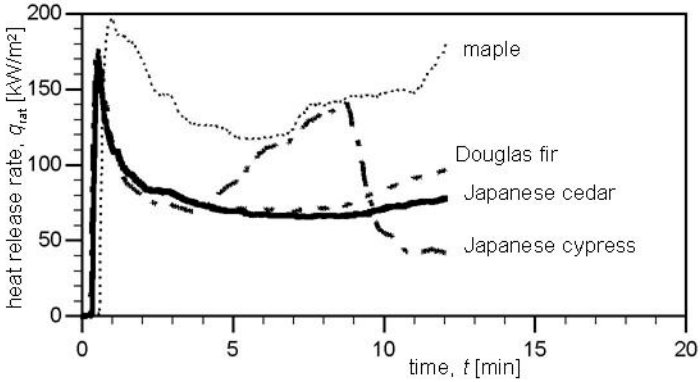


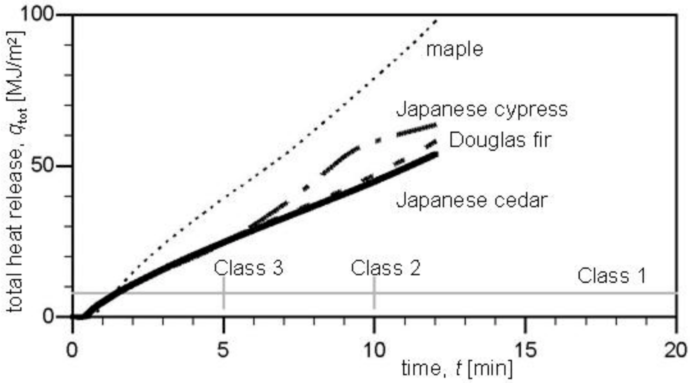
Figure 7. Example of obtained information from cone calorimeter.

3.4. *Result and Discussion of Fire Test*

Figures 8 show results of fire of (a) heat release rate and (b) total heat release for 4 natural woods; maple, Douglas fir, Japanese cedar and Japanese cypress. Only maple is a hard wood and the others are soft woods. The heat release rate just after ignition is very large for these natural woods. Then the heat release rate decreases and is stable for a while. Finally it increases. In the case of Japanese cypress, the heat release rate increases on the way because fire goes around to the back of the sample. Total heat releases of three soft woods are almost same for about 6 minutes after ignition. Figures 8 show the difference between soft wood and hard wood. The heat release rate and total heat release of hard wood are much larger than soft wood. Generally, the density of hard wood is larger than soft wood. The large mass per unit area exposed to fire of hard wood seems to be the cause of the differences. This result shows that the maximum heat release rates of these natural woods are not larger than 200kW/m^2. We are afraid that natural woods cannot clear the condition needed for the maximum heat release in other test samples, because this maximum heat releases close in the 200kW/m^2 just after the ignition. The horizontal gray solid line shows the total heat release of 8 MJ/m^2 in Figure 8 (b). The total heat releases of these four natural woods exceed the line of 8 MJ/m^2 until two minutes after ignition. This result means that natural woods without incombustible chemicals cannot clear the condition needed even as class 3 level fire-proof materials.



(a) Heat release rate



(b) Total heat release

Figure 8. Fire test for untreated natural woods.

Figure 9 shows the result of fire test for developed fire-proof plywood. The heat release rate just after ignition is different from ones for natural woods and it is very small. The developed fire-proof plywood clears the condition required class 1 fire-proof materials on the heat release rate. The total heat release is smaller than 8 MJ/m^2 for 20 minutes after ignition. Figures 10 show samples after heat test for 20 minutes. The developed plywood looks to have no hazardous clacks or holes different from untreated wood. The developed plywood with incombustible chemicals satisfies the conditions of class 1 fire-proof materials defined in Table 1.

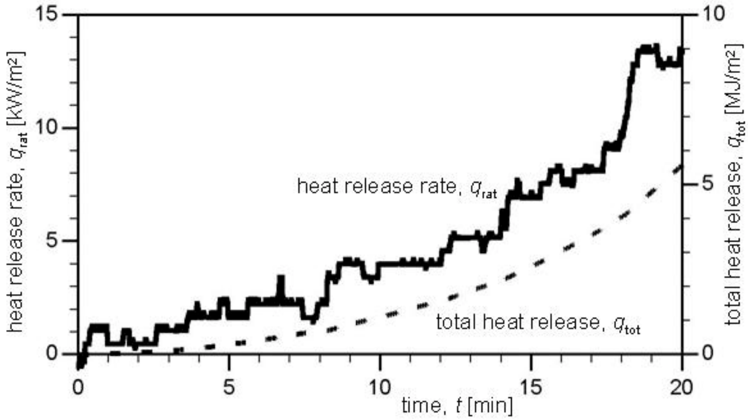


Figure 9. Result of fire test for developed incombustible plywood.

(a) Untreated wood

(b) Fire-proof plywood

Figure 10. Samples after heat test for 20minutes by cone calorimeter.

4 Conclusion

Standardization by Japanese Industrial Standards (JIS) and development of fire-proof wood are discussed as strategies to popularize wood windows. The trend of standardization on wood windows in Europe is searched. The standards of wood windows in Europe seem to have been prepared with schedule for the commitment period of the Kyoto Protocol aggressively and strategically for sustainable development. Detail research of European Standards on wood windows reminds us the difference of climate and wood used for windows between Japan and Europe. According to the information, the research for standardization of wood windows in Japan has just started since 2004 with weather test.

Fire-proof five-plywood made of Japanese cedar, whose each veneer is impregnated with incombustible chemicals, is developed. Fire test is made by cone calorimeter for four natural woods and the developed plywood. Although the natural woods cannot clear the conditions, the developed plywood clears following conditions by Building Standards laws for 20 minutes; (1) Total heat released during the entire test is lower than 8 MJ/m^2 for the required time. (2) There are no hazardous clacks or holes which penetrate into the reverse side. (3) Maximum value of the heat release rate per area is lower than 200kW/m^2 for 10 and more consecutive seconds. The developed plywood can be certificated as Class 1 fire-proof materials by Building Standards laws.

Acknowledgments

We would like to acknowledge the provision of incombustible chemicals and adhesive by Kohmix, Inc. to develop fire-proof plywood.

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TOWARDS A SUSTAINABLE TRANSPORTATION ENERGY SUPPLY

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Global warming has been identified as one of the most important problems facing mankind in the 21st century. Currently, some 6 gigatonnes of CO_2 are emitted each year as a result of the combustion of fossil fuels, and a large fraction of these emissions originate from the transportation sector. By examining the complete energy conversion chain, the choice of primary energy source for any particular application becomes easier to understand. A discussion of alternatives to the internal combustion engine as the sole power source for vehicular propulsion is presented, and some form of hybrid electric vehicle propulsion system is identified as being a likely choice to reduce fossil fuel consumption, and therefore CO_2 emissions from the transportation sector. The demonstrated market success of grid-independent hybrid vehicles may, however, be followed by a new generation of "plug-in hybrid" vehicles in which it is possible to travel for up to 100 km in an all-electric mode, while maintaining the option of using an internal combustion engine when greater range between charging cycles is required. A review of several different design concepts for the plug-in hybrid vehicle is presented, and the way in which these vehicles can be used in conjunction with a sustainable primary energy supply is described.

1 Introduction

The provision of clean, and sustainable, energy supplies to satisfy our ever-growing needs is one of the most critical challenges facing mankind at the beginning of the 21st century. The problem is made even more acute by the huge and rapidly growing appetite for energy in the developing world, many of which are experiencing extremely high economic growth rates, leading to equally high demands for new energy supplies. The growing global demand for energy in all of its forms is naturally putting pressure on the declining supplies of traditional fossil fuels, particularly crude oil and natural gas. However, in recent years no major new production fields have been found, and the exploration effort and cost required to maintain these ratios has been significantly increased. Ultimately, of course, supplies of oil and natural gas will be depleted to such an extent, or the cost of production will become so high, that alternative energy sources will need to be developed. Global climate change, in particular the prospect for global warming, has put the spotlight on our large appetite for fossil fuels. Although there is considerable debate on the extent of the problem, there is little doubt that the atmospheric concentration of CO_2, one of the key "greenhouse gases", is increasing quite rapidly, and that this is likely due to mankind's activities on earth, or "anthropogenic" causes. The utilization of any fossil fuel results in the production of large quantities of CO_2, and most scientific evidence points to this as the main cause of increasing concentration levels in the atmosphere. We must, therefore, develop new long-term methods of strategic thinking and planning, and make sure that some of the best minds, with a wide-range of skills and abilities, are given the tools to do the job. This paper summarizes the current “state of the art” in balancing energy demand and supply, and tries to provide some insight into just a few of the many possible scenarios to build a truly sustainable, long-term, energy future.

2 The Energy Conversion Chain

Every time we use energy, whether it’s to heat our home, or fuel our car, we are converting one form of energy into another form, or into useful work. When we drive a car we are using the engine to convert the chemical energy in the gasoline into mechanical work to power the wheels. This is just one example of the “Energy Conversion Chain” which is always at work when we use energy. In each case we can trace a source of “primary energy” through several conversion steps into the final end-use form, such as thermal energy for space heating or mechanical work to power a motor vehicle. Unfortunately, many proposals to change the ways in which we supply and use energy take only a partial view of the energy conversion chain, and do not consider the effects, or the costs, that the proposed changes would have on the complete energy supply system. A schematic of a generic “energy conversion chain” is shown in Figure 1. We can see that this chain starts with just three possible “primary” energy sources, and ends with a very few end-use applications. It can be clearly seen that hydrogen, which is sometimes promoted as a fuel of the future through the so-called “hydrogen economy”, is not an energy source at all, but only a potential “energy carrier”. In some cases, not all steps in the chain are required, but energy end-use can always be traced back to a primary energy source. For example, in most cases when electricity is the energy carrier it is used immediately upon production, due at least in part to the difficulty of storing electricity.

An important feature illustrated in Figure 1 is the release of emissions, both in the initial processing step and in the final end-use conversion step. Using a conventional motor vehicle as an example, these are primarily carbon dioxide, CO_2, carbon monoxide, CO, unburned hydrocarbon gases, HC’s, and nitrogen oxides NO_x. Some of these are released in the refining process, but most of them are released during the final conversion from chemical energy to useful work in the vehicle’s engine. This emission of pollutants from both the primary energy processing step, and the end-use step, provides an extremely important link between energy use and the environment. The reaction of unburned hydrocarbons and NO_x, in the presence of sunlight, for example, is responsible for smog formation, which has become a major problem in urban centres. This has been alleviated somewhat in the developed world by the introduction of stringent regulations to limit emissions from vehicles and power stations, but will continue to be a very serious problem with the growth in vehicle ownership, particularly in large developing economies. The transportation sector continues, however, to be a major source of greenhouse gas emissions, and the search for a viable source of non-fossil fuel energy for the transportation sector is one of the most important scientific and engineering challenges of the 21st century.

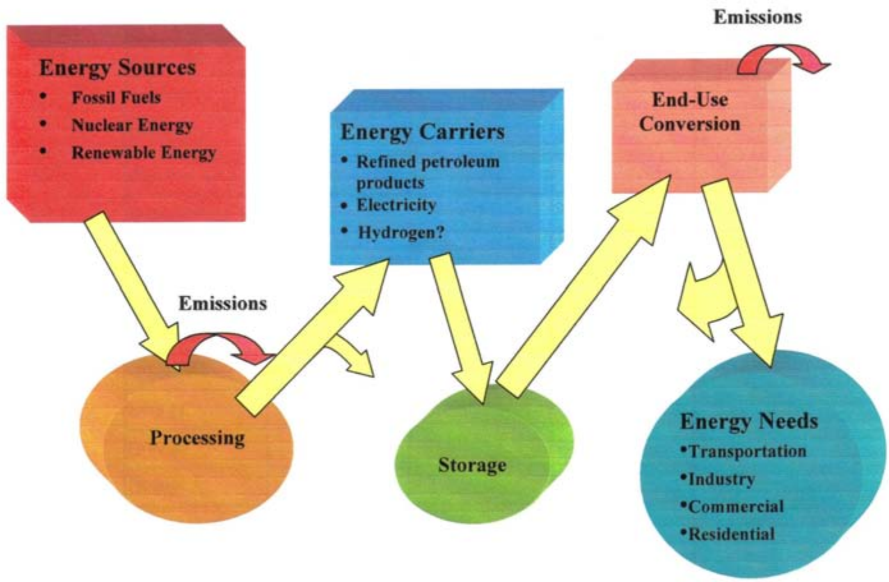

Figure 1. The Energy Conversion Chain

3 Non-Fossil Fuel Energy for Transportation Applications

Liquid petroleum fuels are ideally suited to transportation applications because of their inherently high energy density, and the ease of transportation and storage of these fuels. The internal combustion engine has reached a high level of development, and this is now almost universally used as the power source for all road vehicles. The concern with using petroleum fuels, of course, is that they are derived from crude oil, a non-renewable resource which will eventually be in very short supply. Also, the combustion process produces emissions of nitrogen oxides, carbon monoxide, and unburned hydrocarbons, as well as large quantities of CO_2, the principal greenhouse gas. One way to reduce the dependence of the transportation sector on petroleum based fuels is to switch from the use of internal combustion engines fuelled by petroleum to a completely different form of energy carrier. This has been done successfully for rail transportation by using electric locomotives on lines with heavy traffic volumes which have been "electrified". This is possible for rail transportation since electrical power can be provided continuously to the locomotive through overhead electrical cables, or through a "third-rail" placed adjacent to the tracks. Although this provides a very clean source of energy at the point of end-use, if the electricity is generated primarily from fossil fuels, then there may be no net reduction of greenhouse gas emissions as a result of railway electrification. If, in the long term, the electricity "carrier" is generated primarily from non-fossil fuel sources, such as renewable energy or nuclear power, then there will be a direct benefit through the elimination of greenhouse gas production from the railways. For road vehicles, however, it is not practical to provide electrical power continuously to cars or trucks, and purely electric vehicles must rely on energy stored in an on-board battery. Although electric cars were common during the very early development of motor vehicles, the low energy capacity of batteries made them uncompetitive with vehicles powered by internal combustion engines, and they disappeared from the marketplace.

Proponents of the “hydrogen economy” claim that the use of hydrogen as a transportation fuel would eliminate the production of any harmful exhaust emissions from vehicles on the road. This is, of course, true for the vehicle itself, but as we have seen in our discussion of the complete energy conversion chain, it only represents one part of the complete energy use picture. Hydrogen would just be an energy carrier, like gasoline or electricity is today, and it would need to be “manufactured” from one of the three primary energy sources. If this primary source were to be a hydrocarbon fuel, such as natural gas or coal, all of the carbon in the primary energy source would still end up as CO_2 at the point of hydrogen production. If, on the other hand, the hydrogen produced from a more sustainable primary energy source, such as renewable energy or nuclear power, then there would indeed be no production of greenhouse gases anywhere in the energy conversion chain. The energy conversion chain for using hydrogen in this manner is illustrated by the schematic diagram in Figure 2. This shows the primary energy source being some form of renewable energy, represented by photovoltaic solar cells generating electricity in the figure, but this could be wind-power, or any other source of renewable energy or nuclear power. Following along the energy conversion chain, the electricity would then be used to produce hydrogen by electrolysis of water, and the hydrogen would then be compressed, or converted into liquid form, for storage on board the vehicle. The vehicle would utilize all-electric drive, and a fuel cell would be used to generate electricity on-demand from the hydrogen, which would then be supplied to an electric motor providing the mechanical power to drive the vehicle.

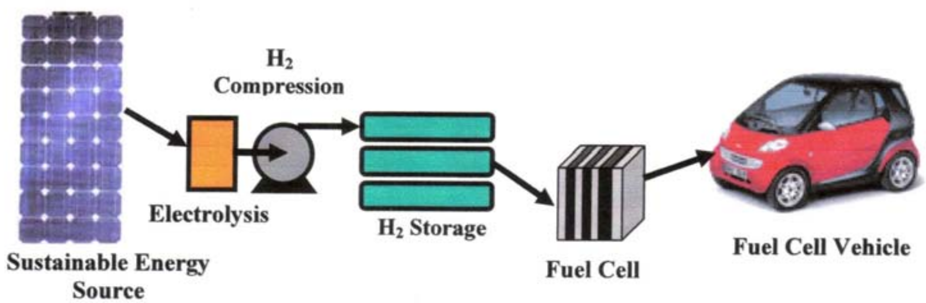

Figure 2. Energy Conversion Chain for a Fuel Cell Vehicle

We can see from Figure 2, however, that the fuel cell is just one major component of the hydrogen fuel-cell powered automobile. A very critical component of the vehicle propulsion system is the fuel storage system on board the vehicle. For a conventional motor vehicle, utilizing an internal combustion engine, this is the simple fuel tank, which stores either gasoline or diesel fuel, both of which conveniently exist as liquid fuels at normal ambient temperature and pressure conditions. At these same ambient temperature and pressure conditions, however, hydrogen is a gas, and this gas has a very low energy density, i.e. one cubic metre of hydrogen gas has a much lower energy content than one cubic metre of liquid fuel. In order to carry a significant quantity of energy on-board the vehicle in the form of hydrogen, therefore, it would need to be highly compressed, or perhaps even liquefied and stored in a "cryogenic" fuel tank at a temperature of around -250ºC. In order to store enough hydrogen energy to provide a reasonable driving range, engineers have proposed using compressed hydrogen at a pressure of 350 bar (5,000 psi), or even 700 bar (10,000 psi). These very high pressures require heavy gas storage cylinders, which would add considerable weight and volume to the vehicle compared to the usual sheet metal container used for liquid fuels. In fact, the storage of hydrogen on board vehicles is one of the most difficult challenges facing the successful commercialization of hydrogen fuelled vehicles. There is also a substantial loss of available energy from both the electrolysis process and the compression of hydrogen for high-pressure storage.

One of the advantages claimed for fuel cell vehicles is the much higher energy conversion efficiency of fuel cells, compared to internal combustion engines. The efficiency of a fuel cell, at around 50%, is certainly much higher than can be expected for the typical internal combustion engine used in motor vehicles. However, if the hydrogen used as the energy carrier on board the vehicle were to be derived from fossil fuels, as it will almost certainly be in any early stage of commercialization of such vehicles, then the overall "well-to-wheels" efficiency is unlikely to be significantly higher than that of the best available technology using a conventional internal combustion engine. This is the conclusion found in comparative studies of vehicle powertrain efficiency by both the Argonne National Laboratory of the U.S. Department of Energy [1], and by researchers at the Massachusetts Institute of Technology [2]. For both of these studies the hydrogen was assumed to be obtained from a refuelling station by reforming natural gas, which would be the most likely source of primary energy, at least in the early phase of fuel cell commercialization. For each vehicle the efficiency of converting the primary energy, either crude oil or natural gas, into the on-board fuel, or the "well-to-tank efficiency", is just under 80% for gasoline, and just over that value for diesel fuel, while for obtaining hydrogen from natural gas the efficiency is approximately 56%. The overall "well-to-wheels efficiency" is then found by multiplying this efficiency by the end-use conversion efficiency (or "tank to wheels" efficiency) of either the engine or fuel cell. The study results show that the overall "well-to-wheels" efficiency for the complete energy conversion chain is just about the same for the best internal combustion engine and hybrid electric vehicle (HEV) configuration and for a simple hydrogen fuel-cell vehicle, starting form the same primary energy source. For the case of a hydrogen fuel cell in a hybrid electric vehicle configuration it is just slightly greater at 29% than the diesel powered HEV at 26%. Also, if the primary energy source was a fossil fuel for both configurations, as assumed in the study, the result would be almost identical levels of CO_2 emissions. It seems unlikely, therefore, that this small gain in overall vehicle efficiency would be sufficient to overcome the much higher cost and complexity of the hydrogen storage system and the fuel cell itself. Advocates of fuel cell vehicles, however, contend that in the long term hydrogen will be produced from some form of renewable energy, as illustrated in Figure 2, or perhaps from nuclear power, which would then result in no emissions of CO_2 for the complete energy conversion chain.

If we examine the case in which hydrogen is generated from a sustainable primary resource, as illustrated in Figure 2, then the first step in the energy conversion chain is the generation of electricity as an initial energy carrier. This carrier is then converted into hydrogen as a secondary carrier, and this is stored on-board the vehicle. The final step in the chain is then the conversion of the stored hydrogen back into electricity by the fuel-cell, and this is then used to power the electric propulsion motor. A parallel situation is used in a simple battery electric vehicle, in which a battery is used on-board the vehicle to store the electricity, as shown by the simple energy conversion chain schematic in Figure 3. In this case there is no need to convert the electricity into a secondary carrier, since the electricity generated as the primary carried is stored directly by the battery, and is then used when needed to supply the electric propulsion motor. The only difference between the scenarios depicted in Figure 2 for the fuel-cell vehicle, and in Figure 3 for the battery electric vehicle, is that in the first case energy is stored in the form of hydrogen, and in the second case in the form of electrical energy in the battery.

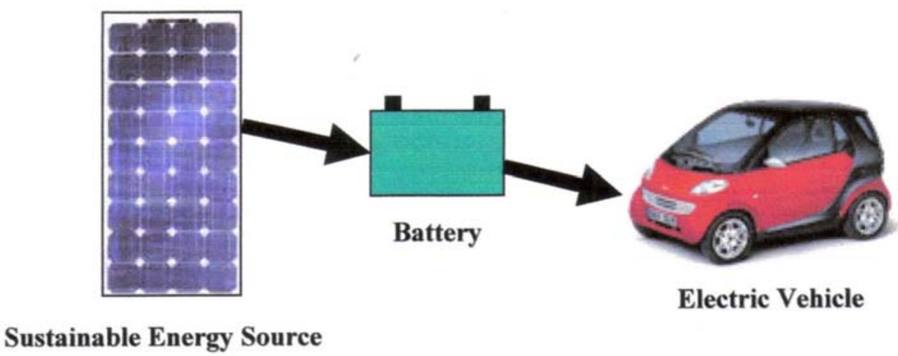

Figure 3. Energy Conversion Chain for a Battery Electric Vehicle

The difference in these two approaches can then be summarized graphically as illustrated in Figure 4. This shows the two different approaches, starting from the point at which the primary energy source produces electricity, and ending where electricity is again used to power the vehicle's electric motor. In other words, all of the equipment illustrated by the conversion chain in the top half of the figure, consisting of hydrogen production by electrolysis, compression, storage in high-pressure cylinders, and finally conversion back into electricity by a fuel cell, is directly analogous to the electrical battery in the lower half of the figure. By making a simple comparison it can be clearly seen that all of the equipment required for the fuel cell vehicle, including hydrogen production and storage and the fuel cell, is really just an electrical energy storage device. The only advantage of this approach over that of using a simple electrical storage battery, therefore, is the hope that the energy storage capacity on-board the vehicle may be greater, or more compact, by using the fuel-cell vehicle route.

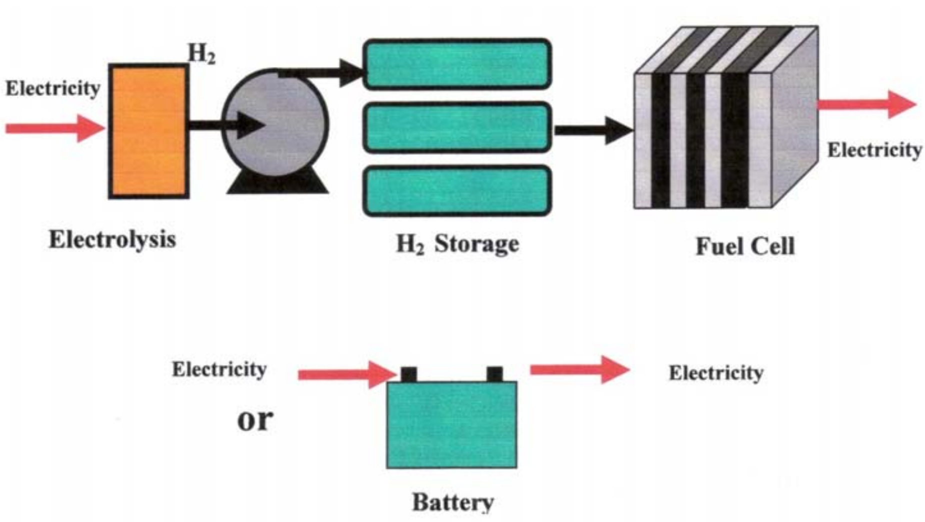

Figure 4. Alternative Electrical Energy Storage Concepts

If electrical batteries were able to store sufficient energy to provide a range of up to 100 miles, then relatively simple battery electric vehicles, which would normally be re-charged overnight, or when not in use for several hours, would likely be attractive to most consumers. Such vehicles would be much less complex and likely much cheaper to produce than the comparable fuel cell vehicles together with the necessary hydrogen production and storage systems. Although hydrogen has a very high specific energy in terms of energy stored per kilogram, because it is a gas it has a very poor energy density, or energy per unit volume, even when stored at high pressure. This means that very large (and therefore heavy) compressed gas cylinders must be used to store a significant quantity of energy. Batteries are not yet able to compete with liquid fuels in terms of either energy density or specific energy, and pure battery electric vehicles will likely be suitable only in specialized short range applications for the near-term future. There continues to be development work on batteries, however, and this has been driven primarily by the successful introduction in the last few years of hybrid electric vehicles (or HEV's). These use a propulsion system consisting of a conventional internal combustion engine, acting as the "prime mover", in parallel with an electric motor and storage battery. All of the energy to drive the vehicle still comes from the liquid fuel (gasoline or diesel fuel) used by the internal combustion engine, but the engine is used to either charge the battery via a generator, or to drive the wheels directly as in a conventional vehicle, or in some combination of both of these approaches. During low-speed operation, and particularly in stop-and-go driving in urban centres, the engine is shut down, and all propulsion is provided by the electric motor being fed from the battery. As the battery becomes discharged the engine is automatically started and again begins to charge the battery, and may also provide some mechanical propulsion directly to the wheels through a gearbox. One major benefit of this powertrain design is that the engine can now operate at its most efficient design condition, independently of vehicle speed or load, thus greatly increasing the overall fuel efficiency. Another significant feature of hybrid vehicles is the use of “regenerative braking”, which utilizes the generator to absorb much of the braking energy normally dissipated in the form of heat by the bakes, and then uses this energy to re-charge the battery. As a result of these design features a hybrid vehicle normally has better fuel mileage during city driving than on the highway, making them particularly well suited to urban commuting. These two features have been developed and refined by automotive engineers so that the hybrid vehicle has a fuel efficiency about 50% greater than that of a conventional vehicle powered by an internal combustion engine alone.

The current design of hybrid vehicles may be classed as “stand-alone”, or “grid-independent” hybrids, because although they incorporate an electrical powertrain, and storage battery, they obtain all of their primary energy from the fuel carried on-board the vehicle, and do not need to be plugged in to the electrical grid to re-charge the battery. However, with the expected advances in battery energy density, and the desire to minimize the use of fossil fuels in vehicles, they may very well be the precursor to a transition to the next generation of hybrid vehicles; the so-called “plug-in” hybrids, sometimes also referred to as “grid-connected hybrids”. A simple schematic of this concept, which incorporates the advantages of both battery electric vehicles and hybrid vehicles, is shown in Figure 5. In this concept, the battery pack in an otherwise conventional hybrid vehicle would be much larger, and could be fully charged when not in use by being plugged into the electrical grid. The vehicle could operate for a significant range, perhaps somewhere between 20 and 60 miles, as a completely electric vehicle, but would still have a small engine to re-charge the battery only when necessary to exceed this distance or perhaps when climbing very steep hills. For many drivers, and certainly for most commuters, the vehicle would then be capable of operating as a pure battery electric vehicle for most trips, and would be plugged in overnight and perhaps also when not in use during the working day. The successful development and introduction into the marketplace of the “plug-in” hybrid vehicle would mark the beginning of a significant new transportation paradigm, that of disconnecting road vehicles from the need to use petroleum fuels, at least for the majority of miles travelled. In considering the complete energy conversion chain for this option, if electricity were to be generated primarily by sustainable primary energy sources, such as renewable energy or nuclear power, then road transportation would also become much more sustainable and would no longer be a significant factor in contributing to greenhouse gas production.

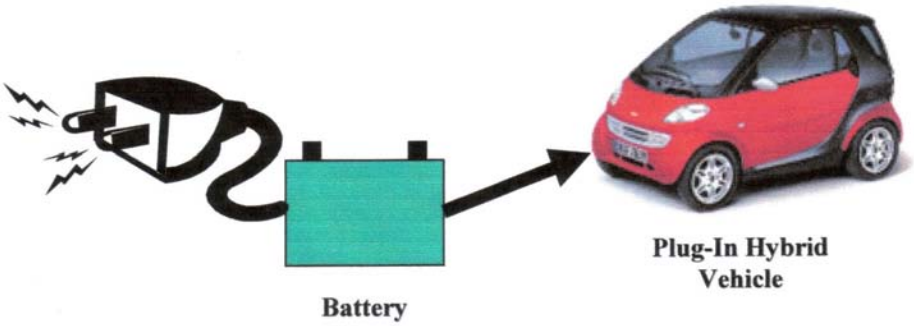

Figure 5. The “Plug-in Hybrid” Electric Vehicle

The Electric Power Research Institute (EPRI) in the U.S. has recently published the results of a study [3] comparing the performance of plug-in hybrid electric vehicles to a stand-alone hybrid vehicle, (or “HEV 0”) and a conventional vehicle powered by a gasoline engine. Two plug-in hybrid vehicle designs were considered, one with an all-electric range of 20 miles (HEV 20) and one with an all-electric range of 60 miles (HEV 60). All of the HEV’s were assumed to use state-of-the-art nickel-metal hydride (NiMH) batteries and regenerative braking, and to have similar performance, including a minimum top speed of 90 mph and a 0-60 mph acceleration time of less than 9.5 seconds. All vehicles were assumed to have sufficient gasoline storage to provide a range of 350 miles. The power split between engine and electric motor is approximately equal for the HEV 0 and the HEV 20, while for the HEV 60 the electric motor has about twice the power of the gasoline. In considering the overall energy consumption of all of the vehicles the study took a “well-to-wheels” approach, and included the energy obtained from the gasoline on-board the vehicle and the energy required to process the crude oil to produce the gasoline, as well as the electrical energy required to re-charge the batteries for both of the plug-in hybrid vehicles, the HEV 20 and the HEV 60. For the battery re-charging part of the process, the study assumed that electricity would be generated from natural gas using a combined cycle power plant, with an overall thermal efficiency of approximately 50%. Many different performance parameters were calculated during the simulation over a standard driving cycle, but the main results of the study were that the complete “well to wheels” CO_2 emissions for the HEV 20 and the HEV 60 were approximately one-half, and one-third, respectively, of that for the conventional vehicle. If, on the other hand, the electricity supply was assumed to be from a sustainable source, with no CO_2 emissions, then the total well-to-wheels CO_2 emissions over the driving cycle, compared to those of a conventional vehicle, would be reduced by two-thirds for the HEV 20, and by some 87% for the HEV 60 vehicle.

4 Conclusion

The need to move from the use of fossil fuels for nearly all transportation applications to a more sustainable energy source will be one of the most important challenges facing engineers in the 21st century. When the complete energy conversion chain for motor vehicle transportation is examined, the use of hydrogen as a carrier does not appear to be particularly attractive. If hydrogen is obtained from fossil fuels, such as crude oil or natural gas, then all of the carbon in the primary source will still end up as CO_2 in the initial energy conversion stage, although there will be no emissions from the vehicle. Only if the hydrogen is made by electrolysis using electricity from sustainable primary resources, such as renewable energy or nuclear power, will there no production of greenhouse gases. This scenario implies, however, that electricity will be used first to produce a secondary carrier, hydrogen, and then this carrier will be returned to electricity on-board the vehicle, using a fuel cell. In this case the complete on-board energy storage and end-use conversion system simply acts like a battery, with electricity both coming in and going out. A more attractive scenario appears to be development of the “plug-in”, or “grid-connected” hybrid electric vehicle, which uses electricity from the grid to charge a battery rather than to generate hydrogen, but maintains a small fossil-fuelled engine as a “back-up” device. Recent studies have shown that using this approach for vehicle propulsion, in which the battery would provide an “electric-only” range of some 60 miles (100 km), would result in a reduction of greenhouse gas emissions by up to 87% compared to those from a conventional fossil-fuelled vehicle.

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URBAN WINDFARMS AND THE PURSUIT OF SUSTAINABLE DEVELOPMENT

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Sustainable Development, a buzzword of the late 20th century, needs to become a reality of the 21st century. This poses challenges for the whole world – from government organisations to individual citizens, we all have a part to play. To ensure that this concept becomes a reality, it requires changes – change in government policies, change in public attitudes and change in the globalisation of the economy. One such area that requires substantial change is that of the global energy production and consumption. Past policies have placed a heavy reliance on the use of fossil fuels, which has proved to be both unsustainable and environmentally polluting. Nuclear power, once thought to be a suitable alternative to fossil fuels, brings its own unwanted legacy. The risks associated with accidents and the problems of safe disposal of nuclear waste continue to cause problems and pose uncertainty for future generations. This paper investigates the potential role that urban windfarms can have in bringing about changes. The progress of the first community owned urban windfarm in Britain is assessed. It will investigate the general publics' attitude to such a project, in comparison to attitudes prevalent towards rural windfarm settings. The analysis of collated data indicates that urban windfarms may have a large part to play in the pursuing the goal of sustainable development. Not only in terms of reducing greenhouse emissions, but they can also subscribe to the three pillars of sustainable development: namely social empowerment, economic improvement and environmental enhancement.

1 Introduction

In 2001 Kofi Annan announced that "Our biggest challenge in this century is to take an idea that seems abstract – sustainable development – and turn it into a reality for all the world's people." (1)Thus to make this concept a reality for all the world's people requires change – change in global strategies, change in government policies and change in citizens' attitudes. This poses difficult challenges as the needs for developing and developed countries are very different, yet both need to be met in a sustainable way. It also requires a shift in global governance to become more inclusive and make the actions and wishes of individuals matter ensuring that they have a greater influence in the decision making processes. Figure 1 illustrates traditional governance in comparison to sustainable governance.

Until developing countries have access to a clean and safe water supply and that poverty is greatly alleviated it is morally unfair to impose pollution and resource restrictions on them. The developed world therefore has a responsibility to these counties to curb their own emissions and resource use and promote good practice that can be universally adopted. This is of particular importance in relation to the global energy market and the adoption of renewable forms of energy.

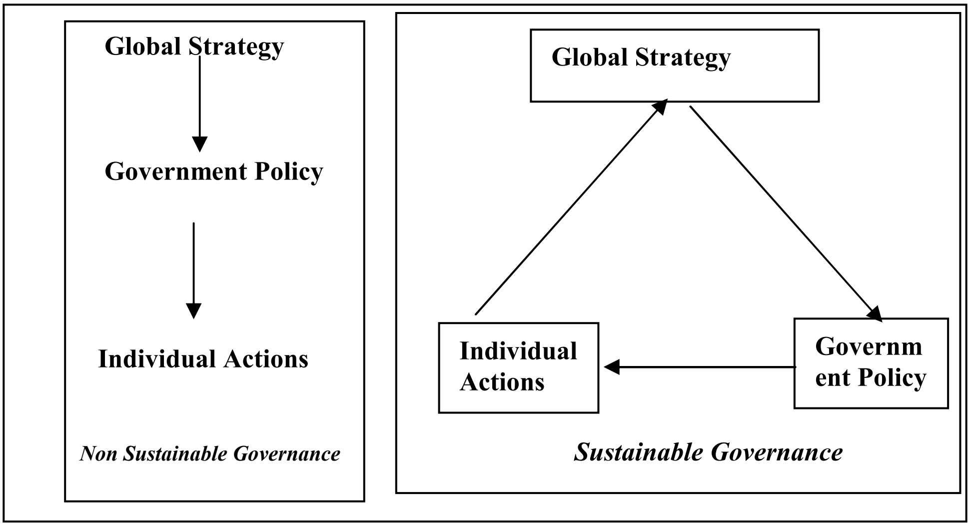

Figure 1. Non sustainable versus sustainable governance in the 21st Century.

2 Global Energy Supply

About 80% of the global energy needs is currently met by fossil fuels (oil: 35%, coal: 23% and natural gas: 21%). Of the remainder, only 5% come form modern renewable sources including hydro and wind power [2]. To become sustainable these proportions need to change drastically. The supply of fossil fuels is not only dwindling, but they also contribute to greenhouse gases and in particular CO_2, the main gas attributed to climate change. The uptake of renewable resources needs to be promoted on an international, national and local scale.

2.1. *Global Initiative*

Global summits such as Rio in 1992 and Johannesburg in 2002 have all highlighted the need for a global strategy and communication to ensure that sustainable development becomes a reality. Despite this it is glaringly obvious that the absence of a mandatory framework hampers the best intentions of many countries. The Kyoto Protocol and the subsequent delay in its ratification, coupled with the obvious absentees have highlighted the main problem associated with voluntary compliance. Sustainability will only be achieved when global compliance is achieved and, until the needs of developing countries are satisfied increased co-operation between developed countries is vital to success.

Despite this drawback, many countries have set admiral targets for the reduction of greenhouse gases, with Britain, and in particular Scotland setting themselves impressive targets both for the reduction of CO_2 and in relation to increased use of renewable technologies to supply their energy requirements.

2.2. *British Targets*

Britain has set a number of targets for the reduction of CO_2, with each country setting their own goals. The Scottish Executive has set two main targets for renewable energy generation. By 2010, 18% of electricity generation should come from renewables, with this figure rising to 40% by 2040. At the moment, 11% of electricity generated comes from large hydro projects, and it is estimated that the 7% necessary to reach the 18% target by 2010 will come from wind projects [3]. Although the majority of these will be large wind farms, it should not be underestimated that small scale projects and stand alone sites can play a very significant part in this process.

3 Wind Power

The UK has the largest potential wind energy source in Europe, with a share of 40% of the total. Despite this, the UK is almost bottom of Europe's wind power league, both in terms of manufacture and installation. In 2004 there were 1,043 onshore wind turbines, covering 84 sites, supplying 0.5% of our energy needs for Britain. This needs to expand rapidly if the goal of a sustainable energy supply is to be achieved, with a target of 1689.7MW set for the end of 2005 (accounting for 1.3% of supply: equivalent to ~ 1 million people) [4].

Scotland has the greater potential to expand both in terms of the actual siting and set up of projects as well as in terms of research and development.

Denmark is home to the largest wind power industry in the world, and houses the biggest wind turbine manufacturer, Vestas. The industry is a huge one, providing employment for over 10,000 people. In 2000, 10% of the country's energy requirements came from wind, with targets for 2025 to increase this amount to over 50%.

Germany has the largest number of wind turbines in Europe and is Denmark's biggest importer of turbines (India is second). The wind industry in Germany provides about 45,000 jobs directly and indirectly and supplies the country with ~6% of its energy needs (14,609MW) [5].

Figure 2 shows the wind turbine distribution in Europe.

The majority of windfarms found both on the continent and further a field are located in rural environments. Due to the fact that these areas are associated with peace and tranquillity there are frequent and often very vocal dissent in relation to any further development plans in a particular area. There is little research carried out relating to urban windfarm settings, mainly due to the fact that there are very few existing examples. However the premise is that the principal objections relating to rural windfarms, namely visual intrusion, effects on the landscape noise will not be applicable to a similar project in an urban setting. This is mainly attributed to that fact that a feature of urban environments is their ability to absorb and cope with change, especially in relation to additions to the existing landscape.

A unique and innovation project is currently underway in Glasgow to investigate such a project.

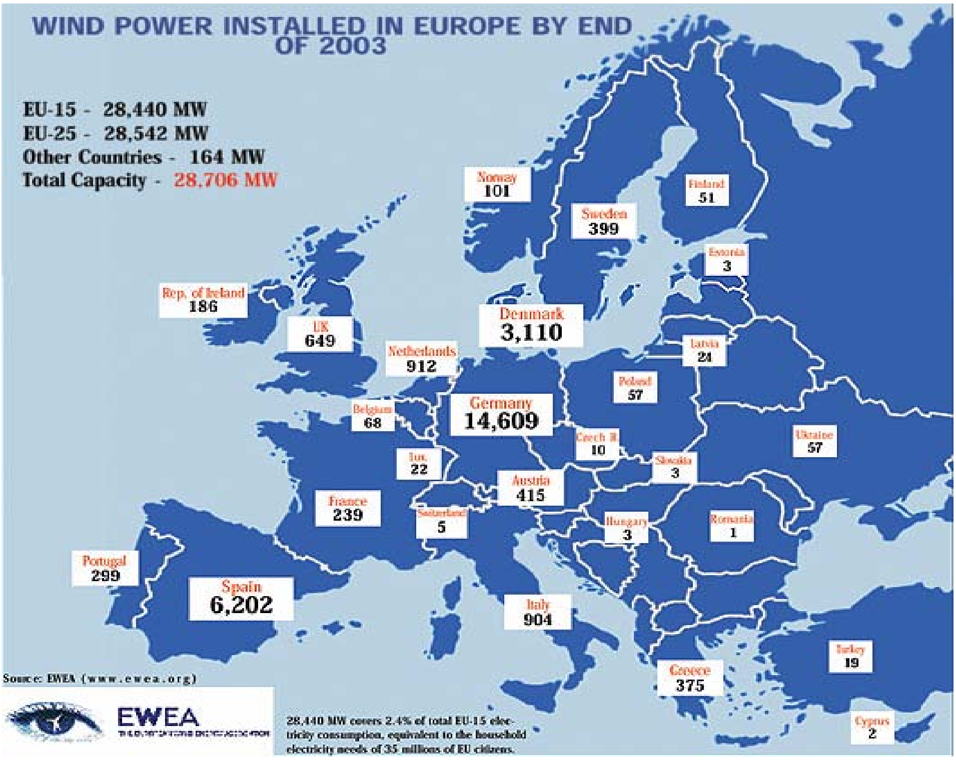

Figure 2. European wind turbine and energy supply in 2003 [5].

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4 Initial Project

In 2001 a project was proposed to investigate the feasibility of an urban wind farm in the Castlemilk area in Glasgow [6]. The aim of the project was to explore the concept of an urban wind farm that would be owned and run by the local people. It was proposed that the project would serve a dual purpose; that of regeneration of a socially disadvantaged area, and provide an educational centre promoting renewable energy, and hence promote the concept of sustainable development.

4.1. *A Brief History of Castlemilk*

Castlemilk, an area to the south of Glasgow has a population of around 14,000 people [7]. The area was built in the 1950's to help solve the problem of overcrowding in the inner city slum areas of the city of Glasgow. It was also hoped that Castlemilk would shorten the waiting list for public sector housing. Traditional industry found a home in the area and provided employment for the majority of the Castlemilk working population.

However following the recession of the late 1970's many of these industries, which had proved to be the backbone of the area were forced to close. The population of Castlemilk was left demoralised and disheartened as the high unemployment levels forced many to seek employment elsewhere. The area became increasingly run down and socially deprived before prompting action to regenerate the area.

This long-term regeneration programme has "the common aim of developing and jointly implementing a comprehensive, mutually agreed strategy."

With this in mind it is hoped that the formulation and construction of a wind farm energy co-op will help address this issue and serve the people of Castlemilk.

4.2. *The Project*

The findings of an initial study indicated that an urban wind farm in the area was in fact possible and identified two possible sites for the farm. It also outlined possible benefits for the local community. As a result of this a further feasibility study of the project was carried out by two academics from the School of the Built and Natural Environment, Glasgow Caledonian University in 2003 [8]. Further detailed study was conducted in 2004 and a wind monitoring mast has since been erected (May 2004) with a view to analysing the wind speeds of the area throughout the year [9].

The Castlemilk community windfarm aims to be the first community owned urban windfarm in the UK. It has been proposed that three 2.5MW wind turbines be erected on the Cathkin Braes, located on the south side of Glasgow, between Castlemilk and the conservation village of Carmunnock (see Figure 3).

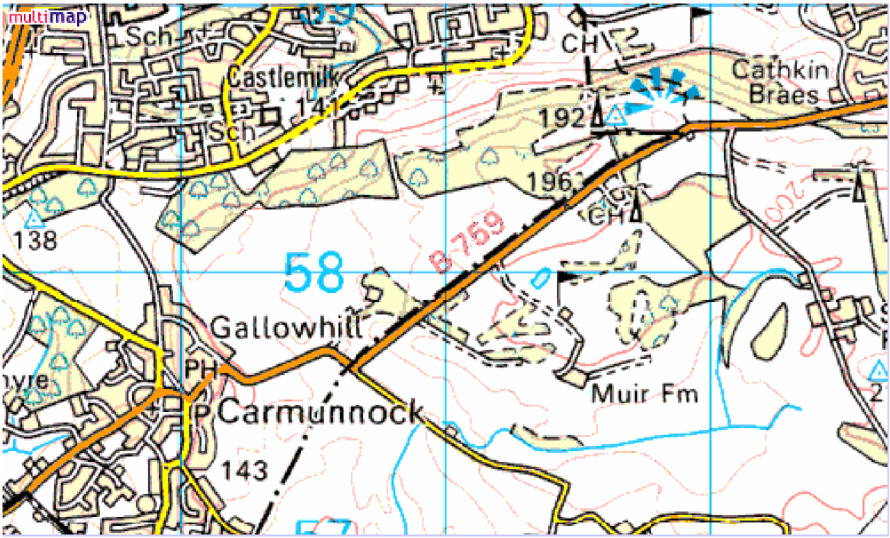

Figure 3. The Castlemilk/Carmunnock area (source: Multimap.co).

4.3. *Community Involvement*

Many projects can attract adverse publicity based on the secrecy of the project. The public object to the fear of disruption and loss of amenities as well as the fact that they played no part in the decision making process. Subsequently if it is found that the site selected is suitable for a wind farm, then the next stage is to consult public opinion. All Castlemilk and Carmunnock residents have been informed of the project and have been invited to attend public meetings where they had the opportunity to voice their concerns and fears about the project. In addition to this there has also been a series of street questionnaires whereby residents shopping in the local shopping centre were invited to express their views on the project. For this particular project it is vital to realise that no matter how technically feasible the project appears to be, it will not be possible unless the people of Castlemilk and Carmunnock fully support it. It is therefore of paramount importance to the success of the project that the views and opinions of the residents are actively sought.

4.4. *Public Opinion*

Analysis of questionnaires obtained at both public meetings and face to face questionnaires show a remarked support of the project. 80% of the responses were extremely favourable, with the main comment being on how the project will directly benefit the community [2]. This is a stark contrast to similar rural projects, where the main concern is how a project may adversely affect the area. The residents of Castlemilk and Carmunnock did not appear to have the same level of concerns as those found in rural areas. No one raised the issue of landscape or visual impact (the most common complaint of these areas), with the main concern relating to increased road traffic. This will only impact on the project at the construction stage, and if managed properly the impact should only be minimal. Figure 4 shows a computer simulated image of the windfarm from a view point in the centre of Castlemilk.

Figure 4. Photomontage showing wind turbines from a view point in the centre of Castlemilk (Entec UK Ltd.).

5 Benefits

The benefits of this project are manifold, but to be attractive to the people of Castlemilk they need to be tangible. What will such a scheme mean in monetary terms for the residents? Estimates from the feasible study indicate that the project will cost £5.2 million to finance, with the most of this money coming from grants and sponsorships. Revenue from the project is estimated to be £250,000 per annum, a profit that will be reinvested in the community in accordance with residents' wishes [9].

In addition to the financial rewards there are a number of additional benefits that the project could bring:

- **Community Ownership** - The aim is for a community led and a community owned urban wind farm that will bring cheaper and cleaner energy to the area. The community will head the project with financial gains being reinvested into the area as the residents see fit. Recent opinions show that the majority of residents feel that the profits should be invested to improve facilities for children and younger people.
- **Attraction of Business to the Area -** The lure of cheaper electricity and the possibility of tax rebates based on using energy from a renewable source may attract businesses to the area. This will aid the economic development of the area and help provide employment for the local residents.
- **Blueprint for Energy co-ops Nation-wide -** If this project is successful it will provide the blue print for the development of similar projects elsewhere. This will in turn give recognition to the area and aid in social regeneration. At the moment there are a number of areas in and around Glasgow that would benefit from such a scheme

with Members of the Scottish Parliament giving the project their backing. Additionally the principles of the project could be adopted on a global scale.

- **Education and Environmental Awareness -** A training and education centre, run by the people of Castlemilk can be set up on site once the wind farm is established. This centre will provide information and allow site visits for schools as well as being the focal point for external parties who wish to know more about the project. Again this will not only increase the environmental awareness of the area but also raise the profile of the Castlemilk area.
- **Visitors/Tourists -** The number of visitors and tourists to the area will rise as word of the uniqueness of the project spreads. This will provide a financial input to the area, thus aiding in the regeneration of the area.

6 Conclusion

Sustainable development requires change and there is no greater area that needs more change than the global energy market. Developed countries need to take the lead in this, creating good practice that can be adopted by developing countries without adversely impacting on the environment. In addition to this there needs to be a change in global governance, with more communication at all levels. Central to this is people empowerment, where individuals can exert a positive influence that affects national and international policies. The concept of a community owned urban windfarm is innovation, novel and exciting and serves as an excellent example for developing countries. In particular it satisfies the principles of sustainability in that:

- People empowerment – giving individuals direct control of projects and active involvement in the decision making process.
- Social inclusion – can regenerate a socially deprived area as well as giving a sense of ownership.
- Economic Gain – any profits from the project will directly benefit the community and not a private developer.

These principles are not unique to urban projects, but can be adapted to suit all communities and promote a society where local residents can directly benefit from the exploitation of a natural local resource (be it wind, solar or hydro). The global potential for similar type projects is huge and should not be overlooked in the pursuit of sustainable development.

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THE NUMERICAL MODELING AS ALTERNATIVE TO PHYSICAL MODEL OF WIND FLOW OVER THE COMPLEX TERRAIN

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This article presents the results of numerical simulation of wind flow over the complex terrain model around the Maslenica bridge in Croatia. The simulation is part of the project whose goal is the proposal of the bridge deck protection from the high wind speed. The Reynolds-averaged Navier-Stokes equations and RNG k-ϵ model of turbulence were numerically solved using the CFD code FLUENT. It was considered the present terrain configuration without the protection and the three different terrain configurations with the differently shaped trench rampart which should protect the bridge deck from a high speed wind. In parallel with the numerical simulation the physical modeling was also realized. The numerical and experimental results showed good agreement.

1 Introduction

Maslenica bridge near the city of Zadar (Figure 1), at the Zagreb-Split highway has been often closed for severe wind conditions. The bridge is subject to strong wind called bura, cold and dry northeasterly wind that blows down from the mountains along the eastern shores of the Adriatic Sea. Bura can achieve speeds in excess of 240 km/h in the bridge area. Maslenica bridge dominant wind direction are at angles in range of 22 to 40 degrees to the bridge axis. Usual wind protection schemes are used where strong winds are perpendicular to bridge axis.

Numerical modeling of bura wind over Maslenica bridge was attempted in order to predict efficiency of several wind protection systems. There were modeled and analyzed three different types of dam as well as referent case without any protection system:

- Referent case without protection system.
- Dam variant A: four 100 m long dams upwind of the bridge at 45 degree angle to the wind direction.

- Dam variant B: a "boomerang" shaped dam of constant absolute height with base perpendicular to the wind direction.
- Dam variant C: a dam of non constant absolute height.

Figure 1. Panoramic view of the Maslenica bridge.

For the analysis, a rectangular footprint of land was considered that is oriented in the direction of the prevailing wind, with upstream distance of 2 km, downstream distance of 1 km and 500 m sidewards from the bridge. Terrain digital elevation model had 25 m horizontal resolution. A computational grid of approximately 2.7 million hexahedral and tetrahedral control volumes was generated. Dimensions of the control volumes varied from 0.5 m in the bridge proximity to over 20 m in domain periphery. The mesh was also progressively coarsened in the vertical direction.

Wind velocity profile at the inlet was unknown and therefore a constant velocity inlet boundary condition of 50 m/s was used. For this particular reason, a large 2 km upstream distance was chosen in order to allow velocity profile to naturally develop and therefore hopefully eliminate impact of unnatural inlet boundary condition on solution accuracy in the area of interest. Other boundary conditions were of "outflow" type. Thus, the domain cross section area reduction in downstream direction did not affect the simulation results.

Numerical simulation was accomplished using Fluent 6 software [1]. Segregated 3d pressure-based solver for incompressible stationary flow with RNG k-epsilon turbulence model [2] was used.

2 Referent Case

Figures 2, 3 represent geometry view of the referent case i.e. surface computational grid of referent case. Simulation results are visualized using velocity magnitude colored path

Figure 2. Geometry view of the referent case.

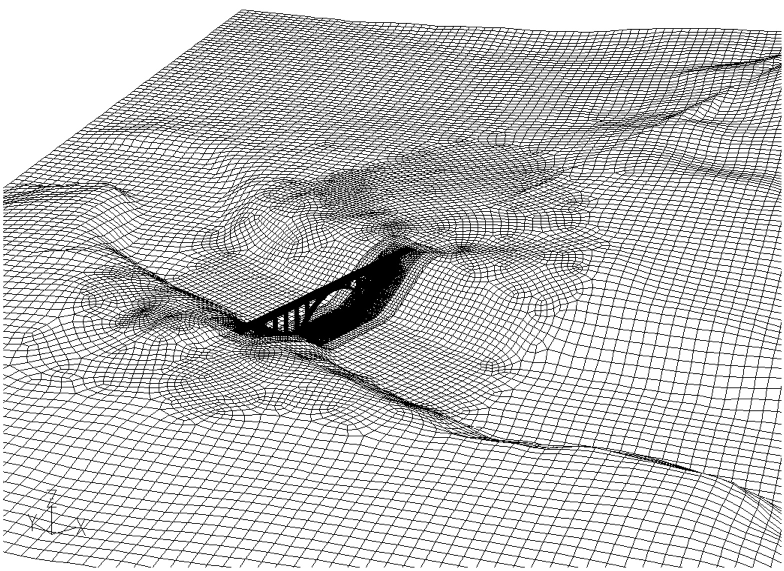

Figure 3. Surface computational grid of referent case.

lines and velocity contour plots in horizontal plane, just above the bridge (traffic lane) surface:

- Path lines graphics give good presentation of 3d flow structures and reveal secondary flows introduced by natural and artificial obstacles.
- Velocity contour plots allow for comparative analysis of different wind protection systems and referent case.

Figure 4 represents velocity colored path lines in Maslenica bridge for reference case, without any artificial flow obstacles. There are visible secondary wind flows bellow the bridge, in the Maslenica channel, represented by blue lines. Those secondary flows partially rejoin with the primary flow at the Zadar end of the bridge and cause local velocity peaks at the bridge end (red spot on the Figure 5). This point will prove itself critical in the following text. Those particles that passed bellow the bridge arc continue down the channel causing no visible flow disturbances.

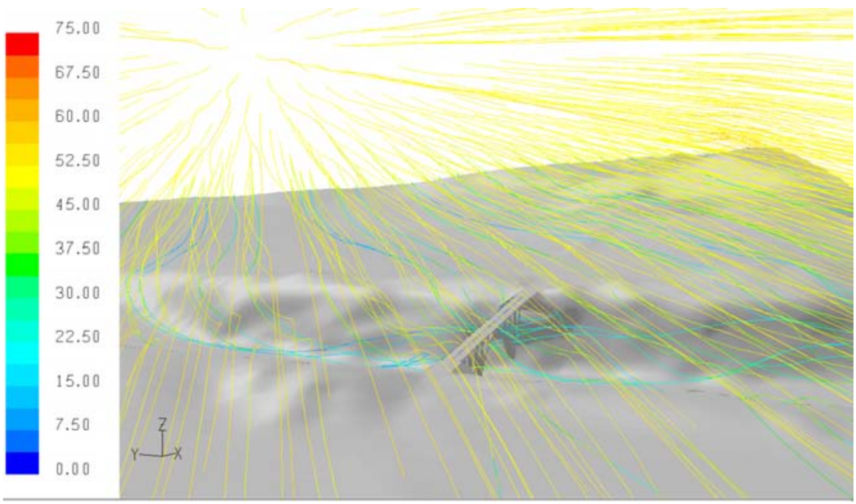

Figure 4. Path lines coloured by velocity magnitude for referent case.

Velocity magnitude contours (Figure 5) reveal that velocity magnitude on the bridge upper surface is generally lower then that of free stream except for the small peak spot near the Zadar end. Also, the velocity field is quite homogenized along the bridge surface.

3 Dam Variant A

Figure 6 represents Dam Variant A. Results for Variant A (Figure 7) show smaller velocities along the bridge surface then in reference case, though there remains peak spot

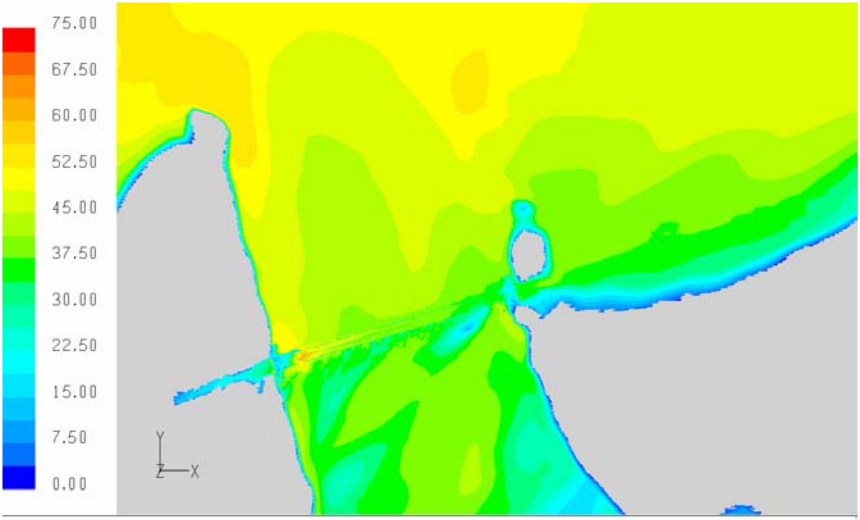

Figure 5. Velocity magnitude contours for referent case.

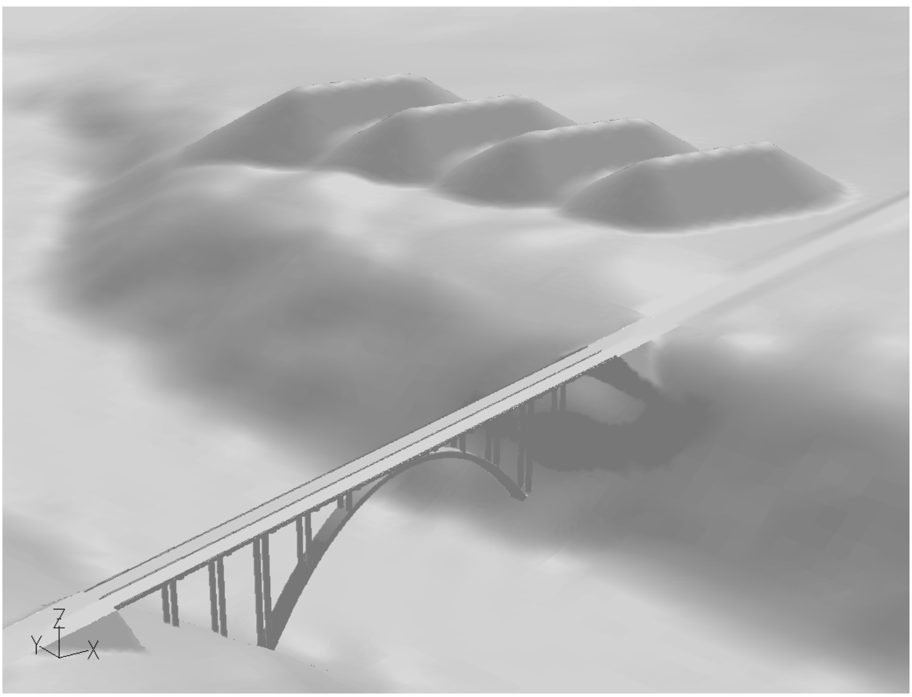

Figure 6. Dam Variant A.

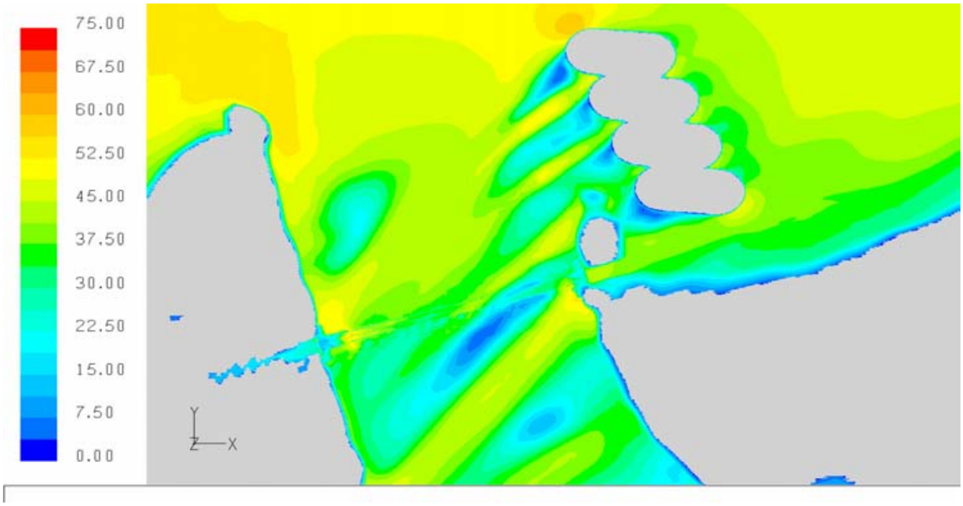

Figure 7. Dam Variant A velocity magnitude contours.

on the Zadar end of the bridge with velocities over 50 m/s (although of lower magnitude then in reference case).

4 Dam Variant B

Figure 8 represents Dam Variant A. Results for Variant B (Figure 9) show big calm but unstable zone behind the dam. There is significant peak spot on the Zadar end of the bridge with velocities over 65 m/s.

5 Dam Variant C

Finally, Figure 10 represents Dam Variant A. Variant C also shows zone of small velocities downstream of the dam (Figure 11). Flow is characterized by great vortices in the slow zone. Peak at the Zadar end around 60 m/s.

6 Conclusion

As already clear from previous text, neither solution delivers acceptable results for not eliminating dangerous velocity peak at the Zadar end of the bridge. Variant C even amplifies velocity at the peak point (Figure 12). Flow behind variant B i C is also characterized by unsteadiness and rotation (Figure 12).

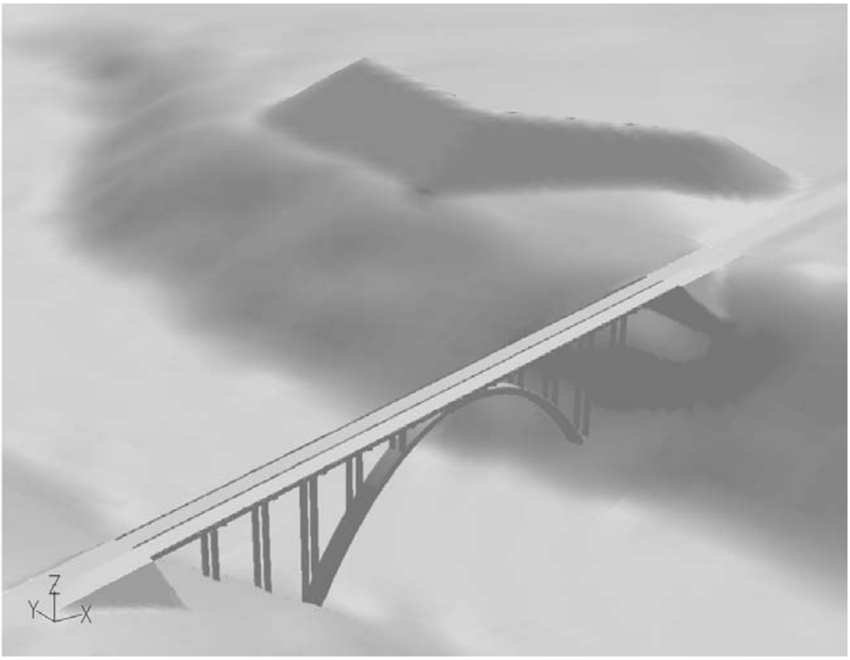

Figure 8. Dam Variant B, boomerang shaped dam.

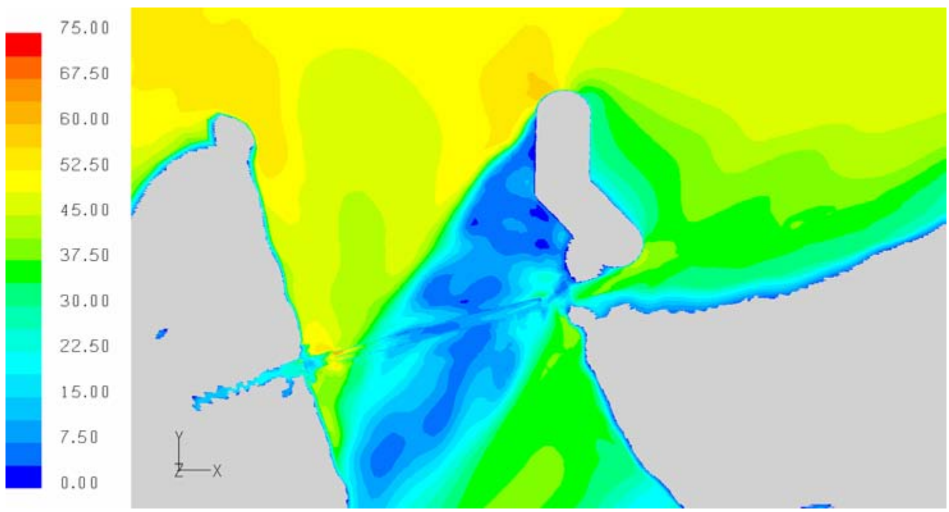

Figure 9. Dam Variant B velocity magnitude contours.

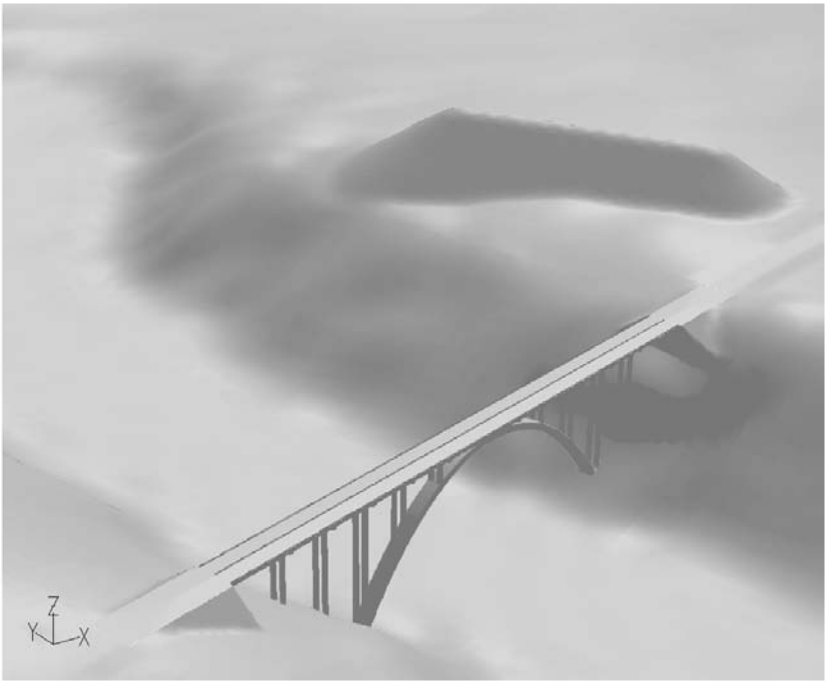

Figure 10. Dam Variant C.

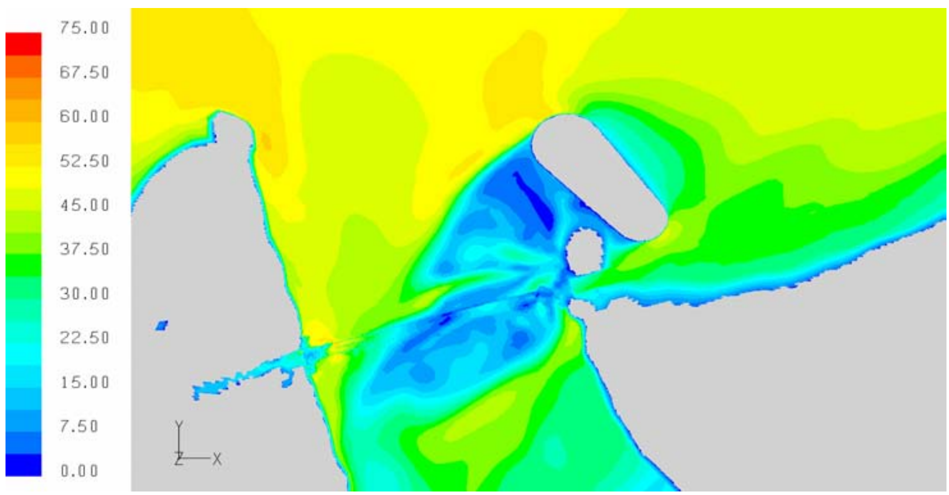

Figure 11. Dam Variant C velocity magnitude contours.

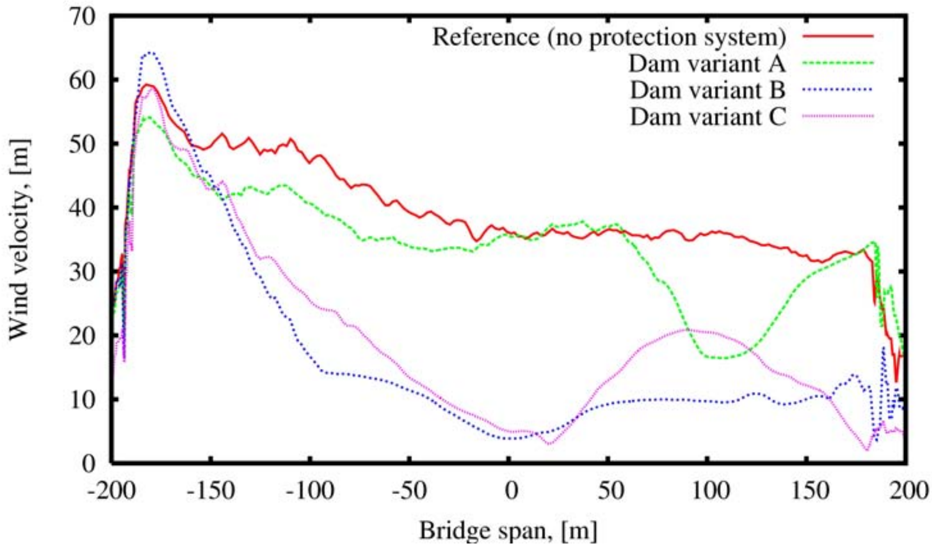

Figure 12. Comparison of velocity magnitude along span of the bridge.

Simultaneously to this numerical modeling, another team performed physical modeling of the same cases experimentally, in the wind tunnel. Although they used slightly different boundary conditions and worked on smaller physical domain and therefore results of the two studies were not directly comparable, they came to the same conclusions. This showed that results of numerical modeling can be accepted and numerical methods used as a tool in engineering.

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BIODEGRADABLE PLASTIC SUBSTITUTE FROM BAMBOO

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The feasibility of applying injection molding method for the production of complex shapes from bamboo was studied. It is necessary for the material to have enough fluidity in the process of molding and bamboo culms were powdered in our early studies. In this study, we pointed out that it was not necessary to grind the culms. It was possible to give bamboo culms enough fluidity to perform injection molding without the powdering process.

1 Introduction

Plastics play a very important role in our lives. It is light, strong, easily molded and durable. However some problems became evident as environmental awareness increases. Plastics are sometimes too durable and once disposed of, it can take decades to break down. Another problem is that traditional plastics are manufactured from non-renewable resources such as oil. In an effort to overcome these shortcomings, many researchers have long been seeking to develop biodegradable plastics that are made from renewable resources. Under the circumstance, we are trying to produce biodegradable plastic substitute from bamboo.

Bamboo takes as little as three years to grow up in controlled forests and considered to be a rapidly renewable resource, which has environmental advantages over long-cycle renewable resource extraction. Despite the advantage, bamboo was utilized only for simple ware making for a long time.

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In our earlier studies [1-2], we powdered bamboo culms and noted the feasibility of the application of injection molding method and extrusion molding method to produce complex shapes. However, the fiber structure of bamboo, which contributes to the strength of bamboo culms, is lost in the process of grinding. In this study, to make the most of the fiber structure, we examined the feasibility of applying injection molding method without the powdering process.

Only bamboo culms were used as raw material throughout the following experiments. No adhesion or additives were added.

2 Material and Method

1.1. *Properties of Bamboo Culms*

Figure 1 shows a transversal section of a culm wall with vascular bundles embedded in ground parenchyma in *Phyllostachys pubescens*. Vascular bundles consist of protoxylem, metaxylem, protopholem, metapholem and bundle sheaths (Figure 2). The bundle sheaths

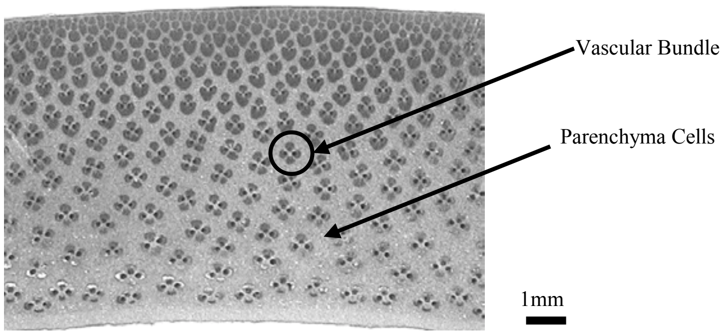


Figure 1. Transverse section of a culm wall with vascular bundles embedded in the ground parenchyma (*Phyllostachys pubescens*).

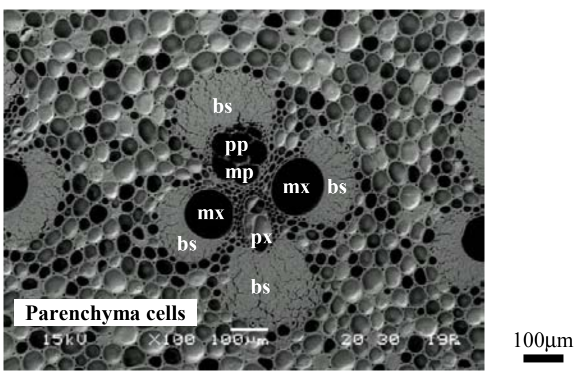


Figure 2. A vascular bundle with protoxylem (px), metaxylem (mx), protopholem (pp), metapholem (mp) and bundle sheaths (bs) in *Phyllostachys pubescens*.

are composed of sclerenchymatous fiber cells. Total culm comprises about 50% parenchyma, 40% fibers and 10% conducting tissue. Figure 3 shows parenchyma cells and fiber cells obtained by soda cooking. The length of the fiber cells is around 1.5mm and the width is around 15µm. The parenchyma cells, forming the basal matrix, are much shorter than the fiber cells with the length around 100µm and the width around 30mm. Bamboo culm consists of about 50-70% holocellulose, 30% hemicellulose and 20-25% lignin [4].

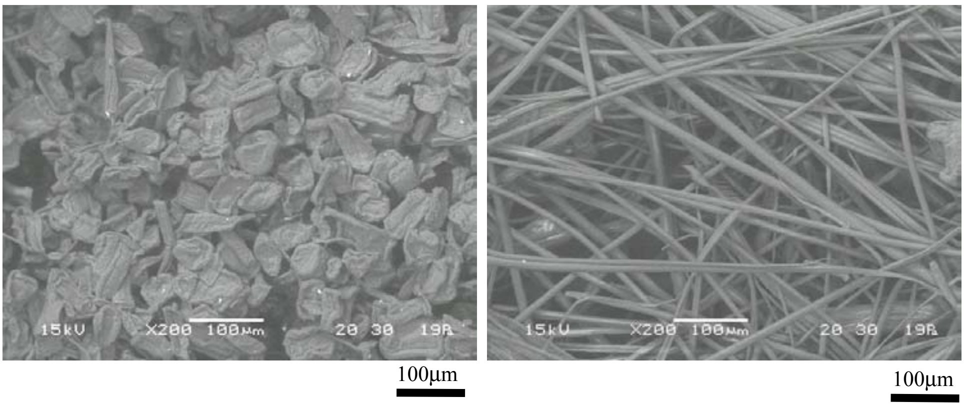


Figure 3. Parenchyma cells (left) and fibre cells (right) obtained by soda cooking.

1.2. *Raw Materials*

Disciform bamboo particles were prepared from air-dry three-year old bamboo (*Phyllostachys pubescens*) culms. The diameter is 29mm, the thickness is about 10mm (Figure 4). The moisture content of the air-dried particles ranged from 9 to 11 percent. Oven-dried bamboo particles were prepared by drying the particles in an oven at 105°C.

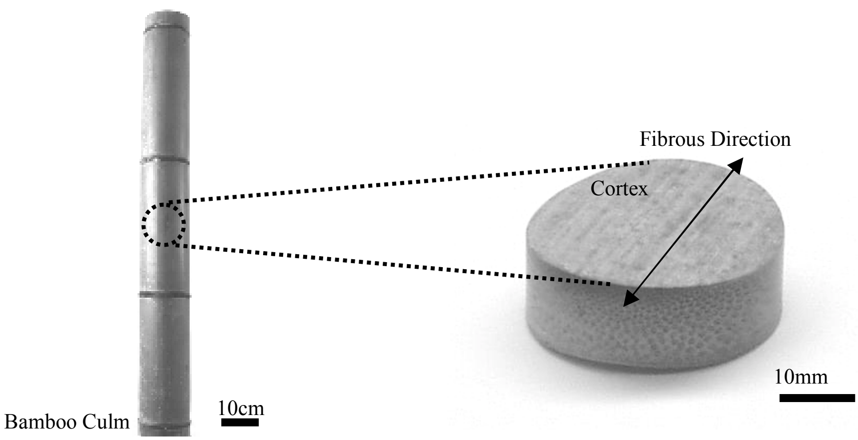


Figure 4. A bamboo particle cut out from a bamboo culm by a circle cutter.

1.3. *Fluidity test of air-dried and oven-dried bamboo particles*

Figure 5 shows the test method applied to estimate the flow properties of the bamboo particles. The diameter of the gate is 2mm, the length is 10mm, the bore diameter of the cylinder is 30mm. The extrusion ratio is 225. After heating the die assembly to the set temperature of 180°C, a bamboo particle of room temperature was put into the cylinder with the cortex side up. Then the piston was placed on the particle and pressed by a pressing machine at 15mm/min. After reaching to the set value of 50kN (71MPa), the load was maintained till the end of the test. The piston moves down as the particle extruded through the gate. The flow properties were estimated by measuring the piston position with a displacement gauge. The origin of the piston position was placed at the point where the piston contacts with the gate. The die assembly was heated by electrically heated platens put on the below the upper and above the lower platens of the press machine. A band heater placed around the cylinder was also used. The temperature of the die assembly was measured by a thermocouple put on the bottom surface of the die 5mm away from the gate end.

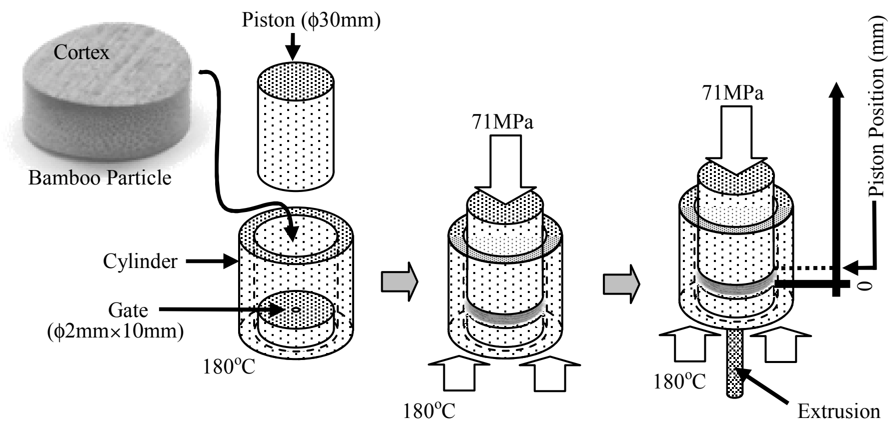
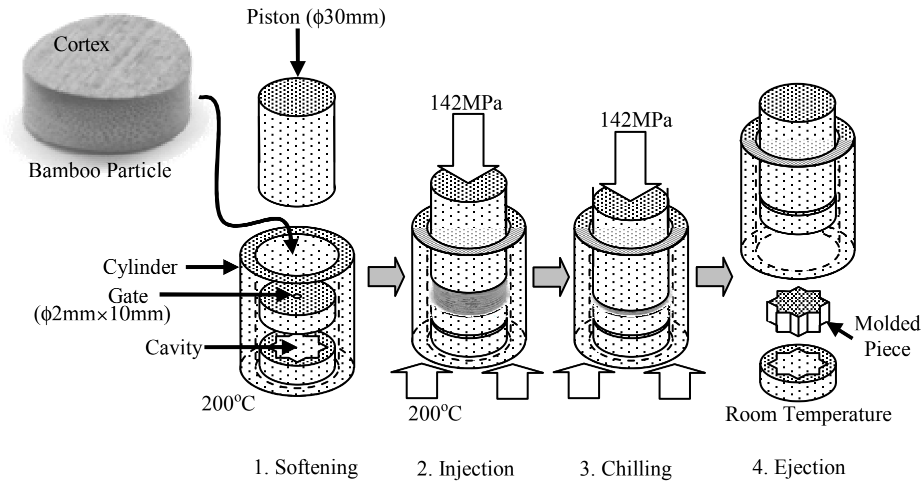


Figure 5. Flow property test method.

1.4. *Injection Molding of Bamboo Particles*

Figure 6 shows the die assembly and the procedure for injection molding. After heating the die assembly to the set temperature of 200°C, two air-dried bamboo particles of room temperature were put into the cylinder with the cortex side up. Then the piston was placed on the particles and pressed by a pressing machine at 15mm/min. After reaching to the set value of 100kN (142MPa), the load was maintained so that the particles flow through the gate and fill the gear-shaped cavity. Then, the die assembly was chilled. The pressure was released after the die temperature reached to the room temperature. The gate size is the same as mentioned in the flow property test.



3 Result and Discussion

3.1. *Flow property of oven-dried bamboo particles*

Figure 7 shows the relationship between time and the piston position on the flow property test of the oven-dried bamboo particle. The particle was compressed as the pressure applied (A-B). No extruding was observed so far. The piston hardly moved for a while (B-C). After about 30 minutes, the piston started to move down extruding the particle through the gate (C-D).

The temperature of the particle is believed to be reached to the set temperature in 2 minutes [2]. Thus, the result that the oven-dried bamboo particle required about 30

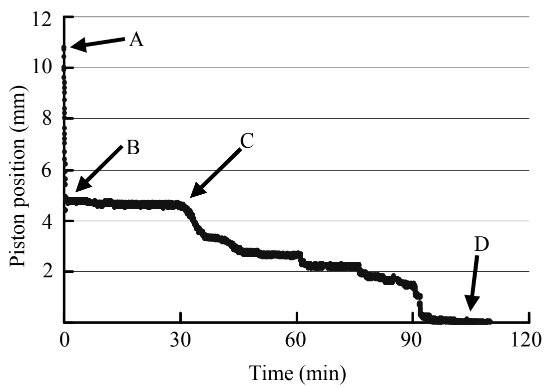


Figure 7. Relationship between time and piston position on the flow property test of the oven-dried bamboo particle (180°C).

minutes to start flowing is not because that the particle required time to reach to the set temperature. The result of our last study [3] explains that this is due to the increase of fluidity caused by thermal decomposition of hemicellulose. Figure 8 shows the extrusion. The surface is flaky and dark indicating severe thermal damage was caused. Fiber cells were observed on the surface and the cut surface of the extrusion while parenchyma cells were hardly recognized (Figure 9).

Figure 8. An extrusion produced from the oven-dried bamboo particles.

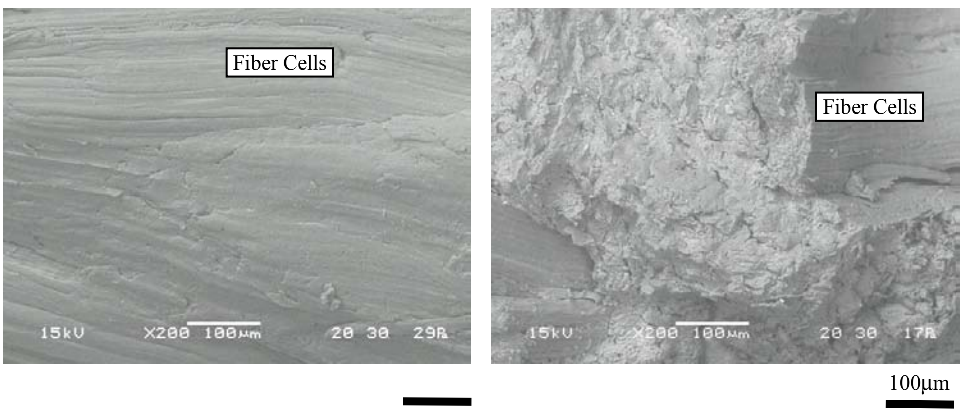


Figure 9. Surface (left) and cut surface (right) of an extrusion produced from oven-dried bamboo particles.

3.2. *Flow Property of Air-Dried Bamboo Particles*

Figure 10 shows the relationship between time and the piston position on the flow property test of the air-dried bamboo particle. The particle was compressed as pressure applied (A-B). The particle started to flow in 2 to 3 minutes (C-D).

As we mentioned in the previous section, the oven-dried bamboo particle required about 30 minutes to start flowing. The difference raises the possibility that water works as a catalyst to decompose hemicellulose. In addition, we should point out that the softening point of the main components of bamboo, namely cellulose, hemicellulose, and lignin are believed to be lower with water. Further work has to be developed to determine the mechanism of the improvement of flow character in the presence of water.

The surface of the extrusion is smooth and pale in colors (Figure 11). Not only fiber cells, but parenchyma cells were observed on the surface and the cut surface (Figure 12). Less damage on the cell structure was observed in comparison with the extrusion produced from oven-dried particles.

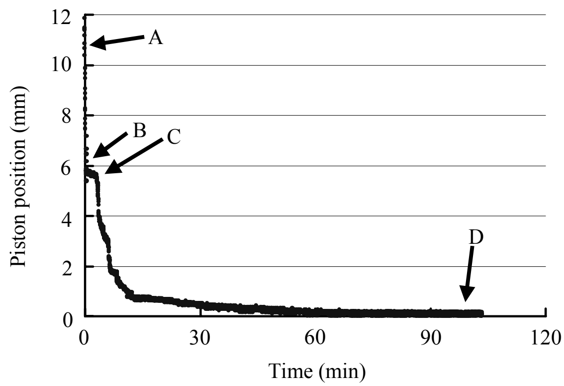


Figure 10. Relationship between time and piston position on the flow property test of an air-dried bamboo particle (180°C).

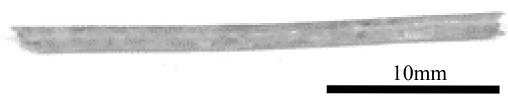


Figure 11. An extrusion produced from the air-dried bamboo particles.

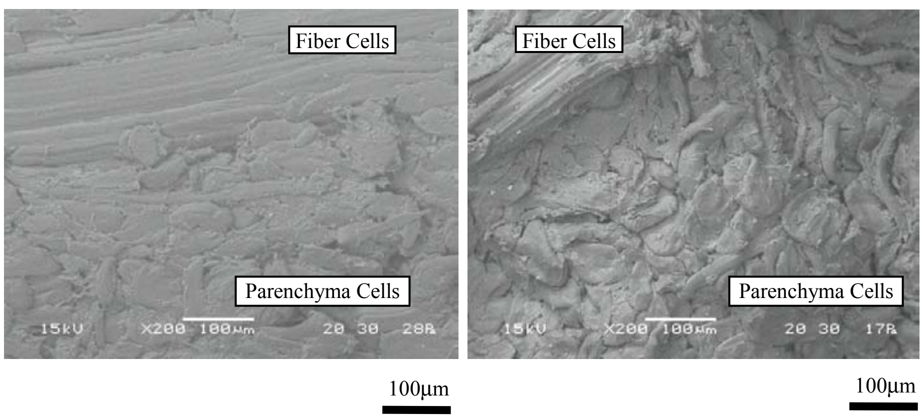


Figure 12. Surface (left) and cut surface (right) of the extrusion produced from air-dried bamboo particles.

3.3. *Injection Molding of Bamboo Particles*

Figure 13 (left) shows the gears produced from air-dried bamboo particles. The complex gear-shaped cavity was completely filled. The surface was smooth with no visible defects. Fiber structure was observed on the cut surface as shown in Figure 13 (right).

The properties of the gears, such as strength, water absorption are yet to be analyzed. However, advantages over the moldings produced from powder are expected by the presence of the fiber structure.

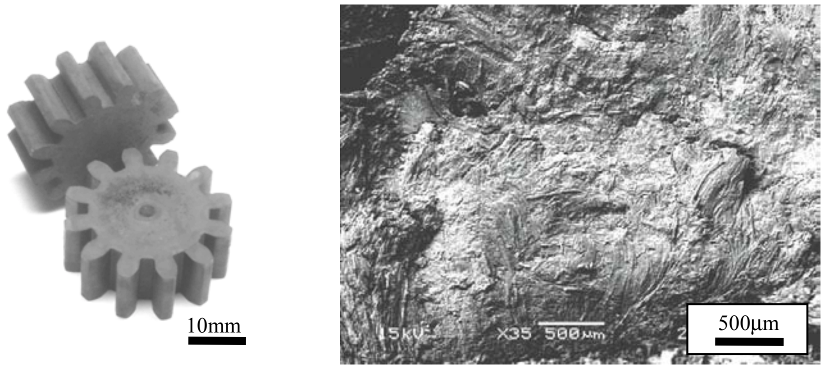


Figure 13. Gears produced from the air-dried bamboo particles by injection molding method (left) and the cut surface of the gear (right).

4 Conclusions

1. It was possible to perform injection molding on bamboo culms without a powdering process.
2. Oven-dried bamboo particles required a certain amount of time to start flowing. This is probably because that it required its hemicellulose to decompose to obtain enough fluidity.
3. Air-dried bamboo particle started to flow immediately.
4. Fiber cells and parenchyma cells were recognized on/in the extrusion produced from air-dried bamboo particles while only fiber cells were recognized on/in the extrusion produced from oven-dried bamboo particles. This indicates the difference of flow mechanism between air-dried bamboo particles and oven-dried bamboo particles.
5. Fiber structure was observed on the cut surface of the gear produced from bamboo particles by injection molding. The fiber structure is expected to improve the mechanical properties of the molded pieces.

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NEW RENEWABLE ENERGY SOURCES AND ENERGY EFFICIENCY

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HYDROGEN FOR SUSTAINABLE DEVELEOPMENT

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Our civilization is facing an unavoidable transition from convenient but environmentally not so friendly, and ultimately scarce energy sources to less convenient, but preferably clean and sustainable ones. Regardless on the energy sources, there will always be a need for convenient, clean, safe, efficient and versatile energy carriers or forms of energy that can be delivered to the end users. Both, hydrogen and electricity are energy carries that together may satisfy all the energy needs of modern civilization. Hydrogen and electricity should not compete with each other, but rather complement each other. With their complementary versatility, they can help in increasing the acceptance and market penetration of renewable energy technologies. However, market penetration of renewable energy sources cannot be left depending solely on market forces. The benefits of a clean and permanent energy system based on renewable energy sources, and hydrogen and electricity as the energy carriers, are reaching far beyond a horizon of an ordinary customer. They are also beyond the horizon of a utility or energy company, and even the nation. The decision on employing the renewable energy sources must be a conscious one, made on a national and international level, and based on clear but far reaching benefits to the nation and to the global environment. This paper attempts to identify and quantify those benefits, with the help of a global energy/environment/economy model based on energy language diagram. Although all economic models are based on growth, from a thermodynamic point of view it is clear that no system based on finite sources can continue to grow forever. A system based on utilization of constant flow of incoming energy (such as solar energy) will eventually reach a steady state. A steady-state level which the human civilization can obtain, depends on the rate of utilization of available solar energy and the effort required to convert solar energy into more useful forms of energy (hydrogen and electricity being only the intermediary steps). The model has been used to predict the level at which the renewable energy sources would be sustainable as a function of timing and net energy (emergy) ratios.

1. Guidelines

Present global energy system is predominantly based on utilization of fossil fuels, coal, oil and natural gas. These fuels make more than 85% of the primary world energy production [1]. These fuels have been relatively easily accessible and have required relatively little effort (or energy) to extract, process and be delivered to the users. Because of that, they have been providing high net energy (or net emergy) to the economic process where they are used, allowing unprecedented economic growth since the industrial revolution. However, there are several problems with the present global energy system, which will only become more pronounced with time:

1) Exploitation of fossil fuels creates pollution on local, regional and global scales. The quality of air in big cities, particularly in developing countries is deteriorating due to exhaust gases from transportation and is causing serious health problems. Most of the scientific community and most of the world countries are now convinced that increase of carbon dioxide and other so called greenhouse gases in the atmosphere is

a direct consequence of combustion of fossil fuels and that it causes global warming with threatening consequences such as global climate change and sea level rise.

2) The reserves of fossil fuels are finite. The exact remaining amount of fossil fuels is subject to vigorous debates but the fact that the reserves are finite is indisputable. In addition, new discoveries do not keep up with increasing projected demand. The world will eventually run out of oil and gas, quite possibly by the second half of this century.
3) Demand for energy will continue to grow, particularly due to rapid economic development in China, India and other developing countries. Energy consumption in developed countries is slowing down due to rational use of energy, but mainly because of shifting high energy intensity businesses and industries to the third world countries. However, energy consumption in China for example is growing because of rapid industrialization and because of increasing buying power of Chinese people. Ever increasing energy demand will keep pressure on energy production and the prices, particularly of oil, will continue to be volatile, and in general will continue to increase.
4) The reserves of oil and gas are unevenly distributed and mainly concentrated in politically very unstable geographic area – Middle East and Arab countries. This will continue to create political tensions and possibly wars over the remaining reserves.

In short, the world will either run out of fossil fuels or will exceed the capacity of environment to absorb the products of their combustion or their uneven distribution will cause global wars over the remaining reserves or they will become unaffordable. The present global energy system is simply unsustainable as illustrated in Figure 1.

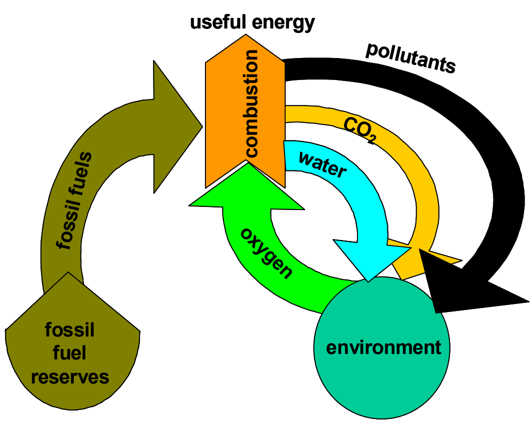

Figure 1. System representation of the present unsustainable energy system based on fossil fuels (adapted from [2]).

2. Hydrogen as future solution of the present energy problems

Hydrogen is a fuel that is by many considered a future solution of the current energy problems. Hydrogen itself is not toxic and its combustion does not create any pollution or greenhouse gases. Hydrogen does not have to be combusted – electrochemical conversion (in fuel cells) is a very efficient way of using hydrogen to provide useful energy.

Hydrogen is a synthetic fuel which can be produced from all and any energy sources including fossil fuels, nuclear energy and renewable energy sources. Hydrogen may be used as fuel in almost any application where fossil fuels are used today – particularly in transportation, where it would offer immediate benefits in terms of reduced pollution and cleaner environment.

Full benefits of hydrogen as a clean, versatile and efficient fuel may be realized only if hydrogen is produced from renewable energy sources. A global system where hydrogen replaces fossil fuels and where hydrogen is produced from renewable energy sources would be in complete balance with the environment, and therefore sustainable, as shown in Figure 2.

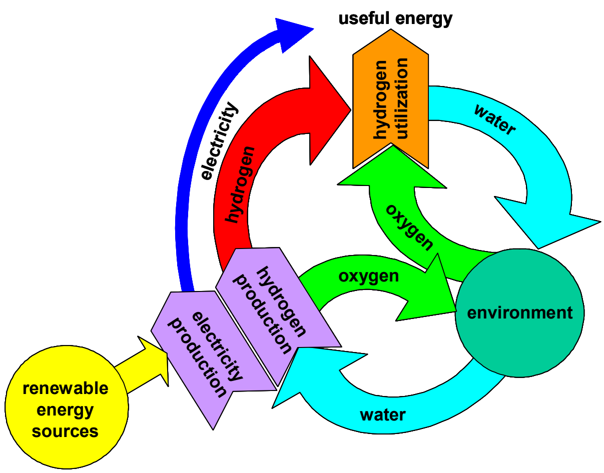

Figure 2. System representation of a future sustainable energy system based on renewable energy sources and hydrogen and electricity as energy carriers (adapted from [2]).

The most developed countries, such as U.S., Canada, EU and Japan have already come up with strategies for transition to hydrogen economy and have already started its implementation. U.S. Department of Energy published A National Vision of America's Transition to a Hydrogen Economy — to 2030 and Beyond [3]. This document summarizes the potential role for hydrogen systems in America's energy future, outlining the common vision of the hydrogen economy. It was followed by The National Hydrogen Energy Roadmap [4], which provides a blueprint for the coordinated, long-term, public and private efforts required for hydrogen energy development. A comprehensive U.S. DOE Hydrogen Posture Plan [5] outlines the activities, milestones, and deliverables DOE plans to pursue to support America's shift to a hydrogen-based transportation energy system. The Posture Plan integrates research, development, and demonstration activities from the DOE renewable, nuclear, fossil, and science offices, and identifies milestones for technology development over the next decade, leading up to a technology readiness milestone in 2015. The plan also points out that the use of hydrogen as an energy carrier can enhance energy security while reducing air pollution and greenhouse gas emissions.

Reducing greenhouse gas emissions, improving security of energy supply and strengthening the European economy are the main drivers for establishing a hydrogen-oriented energy economy in Europe. This is outlined in a High Level Group's report to European Commission [6], which was the starting point for European hydrogen activities facilitated by The European Hydrogen and Fuel Cell Technology Platform (HFP). Series of strategic documents have been created such as Strategic Overview [7], Strategic Research Agenda [8], Deployment Strategy [9] and most recently the Implementation Plan [10].

Several organizations initiate and coordinate hydrogen activities on international level, such as International Partnership for Hydrogen Energy (www.iphe.net) which is mainly focused on developed countries (although countries such as Brazil, China and India are also the members) and UNIDO-International Centre for Hydrogen Energy Technologies (www.unido-ichet.org), which is focused on activities in developing countries.

Although transition to hydrogen economy has undoubtedly already begun, it is still unclear what role hydrogen would play in the future global or regional energy supply. Critiques of hydrogen or hydrogen economy often come from misunderstanding or misconception of hydrogen's role. Individual hydrogen technologies do not make much sense when considered outside the entire energy system.

2.1. *Hydrogen from fossil fuels*

Most of hydrogen is today being produced from fossil fuels, particularly by steam reforming of natural gas and in refineries by partial oxidation of heavier hydrocarbons. However, hydrogen produced from fossil fuels would not solve any of the above listed problems related to utilization of fossil fuels, except perhaps pollution, providing carbon dioxide sequestration is applied at the hydrogen production sites. Arguably, carbon dioxide sequestration could be applied even without hydrogen production (except in transportation, where electricity or some other clean and/or renewable fuels could be used).

Hydrogen produced from fossil fuels, particularly natural gas, as a fuel cannot compete in today's market with the very fuels it is produced from. Hydrogen production from natural gas only makes sense in a transition period to help establish hydrogen supply infrastructure and to help commercialize hydrogen utilization technologies, such as fuel cells.

2.2. *Hydrogen from renewables*

Full benefits of hydrogen as a clean, versatile and efficient fuel may be realized only if hydrogen is produced from renewable energy sources. Hydrogen may be produced from renewable energy sources through a variety of pathways and methods, (as shown in Figure 3), but only a few of them are commercially viable today.

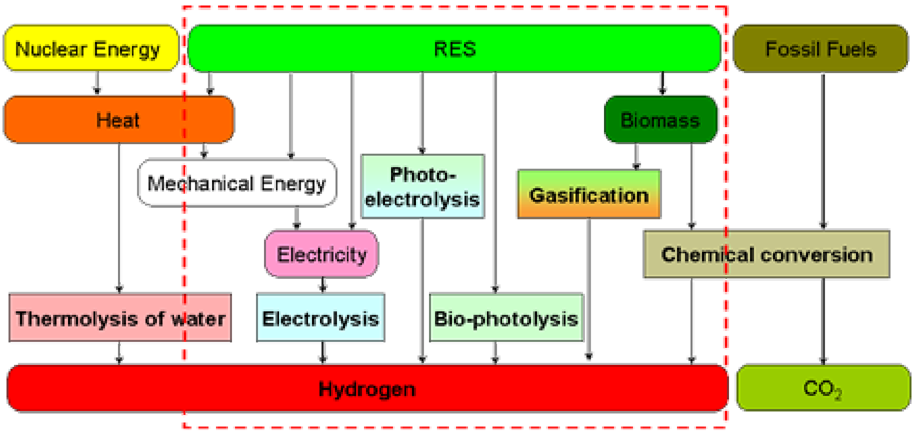

Figure 3. Various possible pathways from hydrogen production (from [7]).

Production of hydrogen from renewable energy sources in most cases involves electricity as an intermediary step. Both, hydrogen and electricity are energy carries that together may satisfy all energy needs of modern civilization. They should not compete with each other, but rather complement each other. With their complementary versatility, they can help in increasing the acceptance and market penetration of renewable energy technologies. Wind energy and solar PV markets are growing at an incredible rate of almost 30% per year. Today there is already 60 GW of installed wind turbine power all over the world [11]. World-wide installed power of solar PVs is more than an order of magnitude smaller but it is expected to reach 88 GW by 2020 [12].

The potential of renewable energy is more than sufficient to supply all energy today's world needs. Today, total primary energy consumption is in excess of 400 EJ/yr. Solar energy received by Earth exceeds this demand by several orders of magnitude. The potential of solar energy over the 1/10 of the World's deserts is estimated at 2500 EJ of electrical energy per year [13]. World hydro and wind energy potentials are much smaller, estimated at 30 EJ/yr each, also expressed as electricity produced (calculated from [14]).

3. Problems with renewable energy sources

It appears that the renewable energy sources have the potential to run the world and that the technology needed to do so is available. Why is this potential only marginally utilized? It is possible to envision world wide utilization of a variety of renewable energy sources, solar, wind, hydro, biomass, and their conversion to heat, electricity and hydrogen. This can be accomplished both locally in small plants and in large centralized plants. Heat, electricity, hydrogen and biofuels generated this way could be produced in quantities to completely replace fossil fuels. There will be no more pollution nor greenhouse gas emissions from energy conversion. Renewable energy is much more evenly distributed around the world and that would reduce the tensions over the remaining reserves of oil and gas. What is stopping us from realizing this vision?

A common answer is: renewable energy is too expensive. This answer keeps open a hope that future development could continue bringing down the cost of technology for utilization of renewable energy. However, if the background of this high cost is analyzed using emergy analysis, the outlook for renewable energy may look less promising. Fossil fuels are a concentrated form of energy and therefore inexpensive because nature has worked millions of years to create them. When we pay for coal and oil we do not pay for this work done by nature – we only pay for human work needed to extract, process and distribute these fuels. In emergy terms, fossil fuels have very high emergy ratio. As a result, utilization of fossil fuels have enabled unprecedented growth of global economy.

The flow of renewable energy has very low emergy compared to fossil fuels. Fuels and energy carriers produced from renewable energy need a lot more work to first concentrate the flux of renewable energy and then to produce them. For this reason they have relatively low net emergy ratio, and because of that, Odum did not believe that renewable energy in general is capable of supporting the society's need for energy [15]. Further studies are required to calculate more precisely the net emergy ratio of renewable energy technologies. The results are expected to vary from technology to technology but also from location to location as already shown in [16] and [17] respectively.

4. Future scenarios

Although utilization of fossil fuels has enabled unprecedented growth of global economy over the last two centuries, this growth cannot continue into indefinite future. The system that is fueling this growth is not sustainable and the growth will have to stop at some point. This may be proved by a simple non-renewable source model using energy systems diagram [18]. If timely transition to new and sustainable energy sources and practices is not implemented the growth will be succeeded by a decline. Such scenarios have been reported by several global models that use energy and the driver for the economic activities [15,19-21].

Because of its low net emergy ratio, renewable energy would have never enabled such growth. A system that is based on utilization of renewable energy eventually results in a steady state. This again may be proved by a simple renewable source model using energy systems diagram [18]. However, if the non-renewable sources are replaced by the renewable energy sources the economic system may reach a steady state at a certain level which depends on the net emergy ratio of these sources. High net emergy would result in a slower growth eventually reaching a steady state at some higher level. Low net emergy would result in a decline, eventually reaching a steady state at some lower level. However, if the human economic society is considered only as a part of a bigger self-organizing system (our planet) with its own patterns, then its sustainability may not be the level steady-state but the process of adapting to the global oscillations [22].

Of course the above mentioned simple models are a very aggregate way of representing global economy and may only be used to conclude on the future trends. Global economy is much more complex and it would require rather complex models to make more accurate predictions. The degree of accuracy of the timescales and the levels of economic activities will depend on the number of parameters taken into considerations, accuracy of data and correctness of the assumptions.

These considerations, based solely on thermodynamics and energy systems diagram, no matter how simple they are, lead to a very serious conclusion: utilization of renewable energy does not support continuous growth. This fact will make any conscious decision on transition extremely difficult. The fact that the present system is not sustainable is not yet given deserving attention. There is a belief that in the future society will find a new energy technology or energy source as it has done in the past, that will continue to support the growth.

Nevertheless, it would be irresponsible to plan our future based on some unknown technology or source. If we are to plan our future based on known energy sources than the only long-term sustainable option are the renewable energy sources: solar radiation and its derivatives wind, hydro and biomass. Hydrogen and electricity will be used to allow utilization of renewable energy in all the sectors – industrial, residential and transportation. With their complementary versatility, they can help in increasing the acceptance and market penetration of renewable energy technologies. Yet, market penetration of renewable energy sources cannot be left depending solely on market forces. The benefits of a clean and permanent energy system based on renewable energy sources, and hydrogen and electricity as the energy carriers, are reaching far beyond a horizon of an ordinary customer. They are also beyond the horizon of a utility or energy company, and even the nation. The decision on employing the renewable energy sources must be a conscious one, made on a national and international level, and based on clear but far reaching benefits to the nation and to the global environment.

The key parameter that will determine the inevitable transitions in energy use and the future of our civilization is the net emergy ratio of the renewable energy sources. It is indeed surprising that this has not been sufficiently studied and analyzed. For any decision on local, regional, national and global transition to renewable energy sources and hydrogen as an energy carrier (together with electricity) it will be absolutely critical to analyze this net emergy ratio. Evaluation of net contributions to the economy that are made by energy sources should account for all energy inputs including the environmental services as well as high quality feedback – services from the economy itself. Emergy accounting is the most comprehensive method that enables summarization of different flows of energy, materials, services, etc., on a common basis. Emergy is a measure of the global processes required to produce something expressed in units of the same energy form.

5. A global model for predicting the future

In order to illustrate the above mentioned scenarios a global energy/environment/ economy model based on energy language diagram has been developed [13, 23]. The model is essentially a two-source model, non-renewable and renewable, with a switch that allows committed large scale utilization of renewable energy (Figure 4). The flows of energy are shown as solid lines and the flows of money as dotted lines (note that money is flowing in the opposite direction from energy). The total money flow is the Gross World Product. The model has been used to predict the level at which the renewable energy sources would be sustainable as a function of timing and net energy (emergy) ratios.

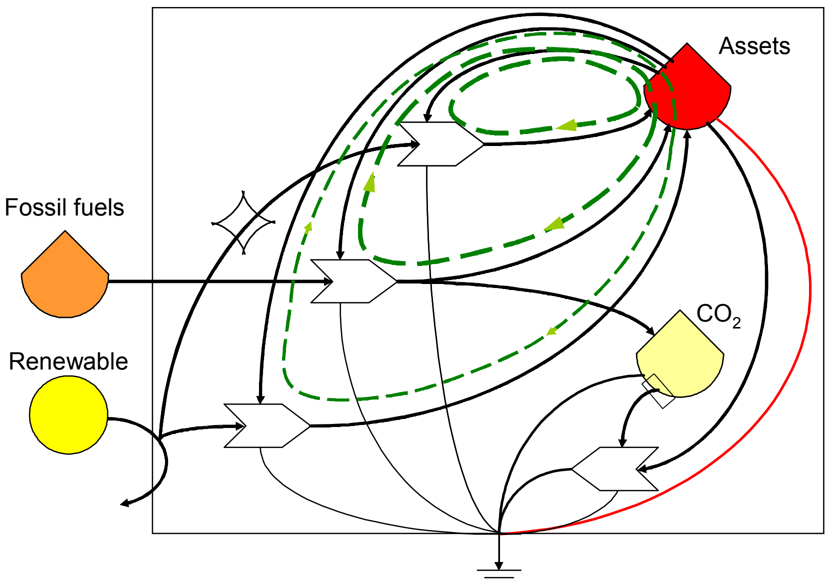

Figure 4. A global energy model (modified from [13]).

How soon the transition should start and how fast should it be implemented? Transition should start before the economy reaches its peak, even if it means slowing down. An early transition may prove to be beneficial in the long term, i.e., it may result in a steady state at a higher level than in case of a transition that starts later (Figure 5). Once the economy starts declining it will not be able to afford transition to a more expensive energy system, and transition would only accelerate the decline.

The model was also used to analyze the effect of the net emergy ratio. Figure 6 shows the results for different cost indices, where the cost index was defined as the ratio of energy cost in the new energy system and that in the present one. Higher cost index would mean lower net emergy ratio.

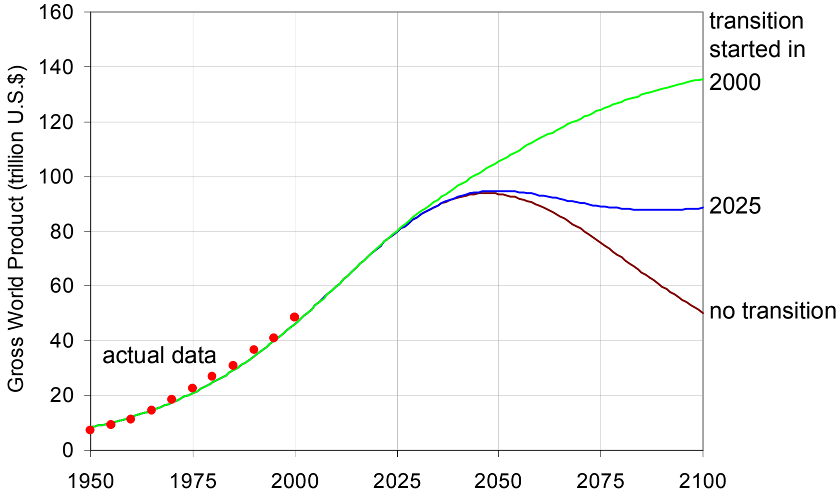

Figure 5. Effect of timeliness of transition to renewable energy/hydrogen energy system on global economy (in 2004 US $) (updated from [23,24]).

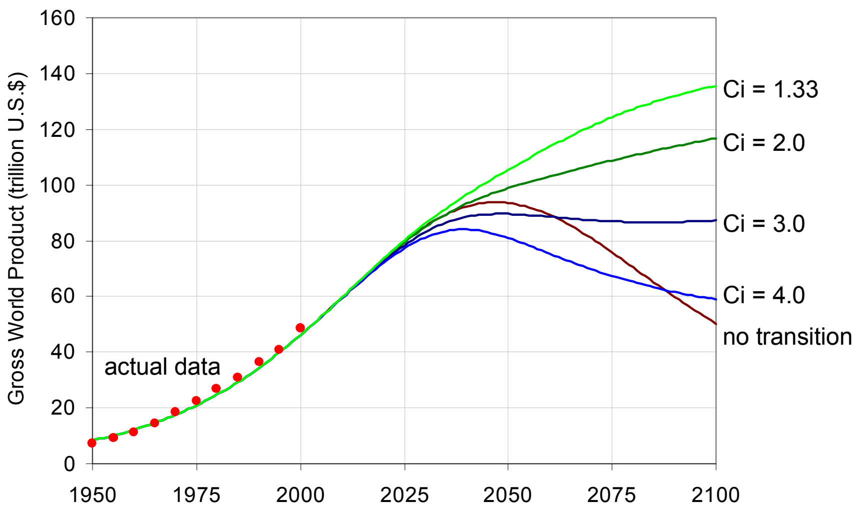

Figure 6. Effect of the energy cost in the renewable energy/hydrogen energy system on global economy (in 2004 US $) (updated from [23,24]).

The answer to question "how fast" is more complex. Major transitions in the past took several decades. If a transition is too fast it may weaken and drain economy too much and may result in a lower steady state. If a transition is too slow, global economy may be weakened by the problems related to utilization of fossil fuels (such as global warming and its consequences) and the result again would be a lower steady state. Therefore, there must be an optimal transition rate, however its determination would require very complex models and constant monitoring and adjustment of parameters.

Another difficulty is that such a transition must be conducted on a global level. Any country that attempts to forcibly switch from fossil fuels may put itself in an inferior economic position for decades. This is particularly a sensitive issue for developing countries. It would be relatively easy to establish a new energy infrastructure in the countries that a) need little energy b) do not have an energy infrastructure in place. However, use of renewable energy sources may hinder their economic growth and would only make the gap between the rich and poor countries even bigger.

6. Conclusion

Hydrogen is a fuel that is by many considered a future solution of the current energy problems. The most developed countries have already come up with strategies for transition to hydrogen economy and its implementation is already underway. However, full benefits of hydrogen as a clean, versatile and efficient fuel may be realized only if hydrogen is produced from renewable energy sources. A global system where hydrogen replaces fossil fuels and where hydrogen is produced from renewable energy sources would be in complete balance with the environment, and therefore sustainable. Competitiveness of renewable energy sources and their carriers, including hydrogen, will depend on the net emergy ratio of the production process. Renewable energy sources in general have less emergy than the fossil fuels, and they will not be able to support continuous economic growth, and will eventually result in some kind of a steady-state economy. An early transition to renewable energy sources and hydrogen may prove to be beneficial in the long term, i.e., it may result in a steady state at a higher level than in case of a transition that starts later. Once the economy starts declining it will not be able to afford transition to a more expensive energy system, and transition would only accelerate the decline. Similarly, if a transition is too fast it may weaken and drain economy too much and may result in a lower steady state. If a transition is too slow, global economy may be weakened by the problems related to utilization of fossil fuels (such as global warming and its consequences) before transition is completed and the result again would be a lower steady state. Therefore, there must be an optimal transition rate, however its determination would require very complex models and constant monitoring and adjustment of parameters. The decision on employing the renewable energy sources must be a conscious one, made on international level, and based on clear but far reaching benefits to the global economy and to the global environment.

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RENEWABLES AND HYDROGEN FOR DEVELOPING COUNTRIES: A CASE-STUDY OF PERU

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The paper propose the sustainable energy use of sugar cane trash taking into consideration the concept of Closed Cycles of Energy Resources – CCER, whose goal is to achieve zero consumption in terms of non-renewable resources and no impact on the environment. The study is focalised to illustrate that innovative bioenergy systems are thermodynamically possible and that its would reach a very high efficiency. The suitably design and implementation of modern bioenergy system contributes to sustainable development, due to integrate technical feasibility with environment and socio-economic assessment. The proposed bioenergy systems are analysed for Pucalà sugar factory, Chiclayo (Peru), starting from current situation to the modern technology. The technological power plant is constituted by a indirect heating fluidised bed gasifier, a hot gas cleanup system and a Molten Carbonate Fuel Cell (MCFC). This system presents the higher electrical efficiency for the sugarcane trash. Furthermore, that is feasible the production of hydrogen rich gas from sugar cane residues (leaves, tops and bagasse) to be used in fuel cell systems. The investment and operational costs regarding the use of fuel cell, are higher than in other possible technological solutions if related to the amount of processed biomass, but are the lowest if referred, as usual, to the produced kWh. Moreover, since the technologies used are in the research and development phases, the costs are expected to dramatically decrease in the near future.

1 Introduction

The accomplishment of energy cycles that use renewable energy sources and don't create any "pollution-waste" are required to insure the human sustainable development. Currently, energy chains deplete resources that are not able to reform and release harmful pollutants, creating local and global pollution and waste. Therefore, the target is that a energy chain that begin from a renewable resource, be able to completely "close", with no resource consumption and no impact on the environment. On this way, the research activity of CIRPS is focalised in the assess of CCER, concretely hydrogen chain.

One of these renewable resources is the biomass. The biomass resources including organic waste streams, agricultural and forestry residues, as well as crops grown to produce heat, fuels, and electricity. Biomass contributes significantly to the world's energy supply. The modern use of biomass to produce electricity, steam and biofuels is estimated at 7 exajoules a year.

The resource potential of biomass energy is much larger than current world energy consumption. With agricultural modernised up to reasonable standards in various regions, and given the need the preserve and improve the world's natural areas, 700 to 1.400 million hectares may be available for biomass energy production well into 21st century.

The availability of land for energy plantations depends on the food supplies needed and on the possibilities for intensifying agricultural production in a sustainable way.

Regarding the production of heat, in developing countries the development and introduction of improved stoves for cooking and heating can have a big impact on biomass use.

For the electricity production the application of fluid bed combustion and advanced gas cleaning will allow the efficient production.

2 Biomass for energy use

Biomass is the fourth world-wide energetic source. The exploit of biomass energy systems contributes to a positive social and economic impact (poverty alleviation, creating opportunities for income generation, gender impacts, land use competition and land tenure, etc.).

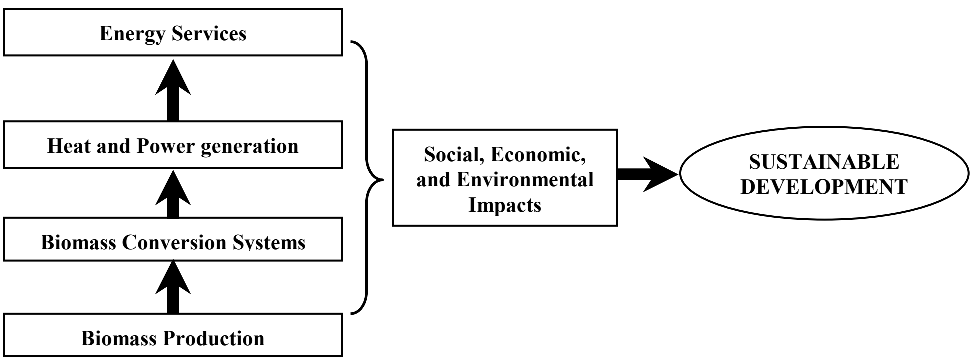

Figure 1. Biomass for energy use and sustainable development

Furthermore, about the environment impact, the use of biomass energy systems has the potential to reduce greenhouse gas emissions, the net emission of carbon dioxide will be zero as long as plants continue to be replenished for biomass energy purposes.

Then, the biomass energy systems support the sustainable development. The energetic use of the refusals involves a careful study of the characteristics of the territory, of the place where to settle the power plant (not distant from the biomasses to be used), of the reliability of supplies and of the integration of the different phases: production, collection, transport, storing, pre-treatment, conversion and distribution should coexist in a unique context (Energy Farm).

On the current situation biomass represents the 3% of primary energy consumption in industrialized countries. However, much of the rural people in developing countries is dependent on biomass, mainly in the form of wood, for fuel. In developing countries, biomass signify the 35% of primary energy consumption.

Biomass differs from other alternative energy resources in that the resource is varied, and it can be converted to energy through many conversion process.

Goods results about the sustainable use of the biomass for energetic purpose are in Brazil (Alcohol Programme), Nicaragua, Sweden, Mauritius, etc.

A classification of biomass for energy purpose regards the modern biomass and traditional biomass. The modern ones involve large scale uses and aims to substitute for conventional energy resources (agricultural residues, urban wastes, biofuels, energy crops). Traditional biomass is normally indicate for small scale use (domestic use, plant residues, animal wastes).

3 Sugarcane, bagasse and sugarcane trash

The biomass in study is the sugarcane (see Figure 2). The **sugarcane**, herbaceous cultivation with times of cultivation of six months, is one of the biomasses that more are adapted to being used for energetic. The sugarcane has the highest rate of energy produced for hectare between all the cultivation (productive ability 50-100 t/ha, CV 18 MJ/kg); a rich typologies of waste to high energetic content (bagasse and barbojo); no production and transport costs, since that the waste are both produced and used in the factory: the only cost is due to the collection of the barbojo; favourable conditions of the enterprises (fallen and oscillations of the price of the sugar); favourable characteristics of cultivation (warm-humid climates, small demand for pesticides and chemical fertilisers); has an important potential for the human sustainable development and modernisation on a larger scale in developing countries.

Today the **bagasse** (sugarcane by-product that is generated in quantities abundant in the mill process).is used at mills as a fuel by combustion to generate combined heat and power (CHP). The combined CHP systems generate the process steam and at least the great part of the electricity for the mill.

Additionally, the tops and leaves (**barbojo or sugarcane trash**) have the energetic potential for the use as a fuel, facilitating the operation of the plant around the year. This “barbojo” is typically burned on the fields to facilitate harvesting and replanting.

4 The sugarcane process

The sugarcane is harvested by hand cutting method or by mechanical harvesters. After cutting, the cane is loaded by hand, mechanical grab loaders, or continuous loaders and then is transported to the mills using trailers, trucks, railcars, or barges, depending upon the relative location of the cane fields and the processing plants.

Figure 2. The Sugarcane

Sugarcane processing is oriented on the production of sugar (sucrose) from sugarcane. Other products of the processing include bagasse, molasses, etc. Bagasse in several developing countries is used for fuel for the boilers and production of numerous paper and paperboard products. Bagasse and bagasse residue are primarily used as a fuel source for the boilers in the generation of process steam.

We are focused in the energetic analyses of the process: electricity and steam process production. In the old mill plants the steam process is produced by the use of boilers with low efficiency (50%, Chiclayo – Peru) so the electricity requirements are insured in part. The deficit of energy is obtained buying from the grid. In modern mill plants the configuration of the plant is determined by the use bagasse in high efficiency modern boiler (70-80%, Mauritius, Brazil, etc.) and a condensing extracted steam turbine or back-pressure turbine. This configuration normally permits a surplus of electricity that can be gathered and sold to the grid. This kind of modern plant and the other possible technical solutions will be considered in this paper.

For the case study that we assess, the sugar mill of Chiclayo – Peru has five boilers for the steam generation with more than 50 years of operation and then, the performance and efficiency is poor. The steam expands into back-pressure turbine and after that is carried to the process. Then, is possible identify technical solutions to raise the efficiency of the plant and optimise the use of bagasse and barbojo, according with the current bioenergy systems and experience in other sugar plants. CIRPS has a scientific-cultural cooperation programme with universities in Peru and realised the joint-study of this possible technical solutions for this sugar plant.

But, in Peru as in other countries, the absence of regulations make it unattractive for sugar industries to invest in more efficient power generation. Currently the economy of

Peru is strongly based on the use of Camisea gas project and the promotion of hydroelectric projects.

The Pucalà cane sugar production plant has 2,500 employees; produces 905,300 t of sugar cane (80 t/h), 633,724 t (187 t/h) of worked cane, 64,640 t of produced sugar. The plant, situated near Chiclayo in the north coast of Peru, currently burns the barbojo in the fields and uses bagasse in low efficiency boilers for process steam production. This makes that the plant is not energetically self-sufficient and buys energy from the grid. A general view of the plant can be seen in the figures 3 and 4.

Figure 3. General View of the Pucalà plant

Figure 4. General View of the Pucalà plant

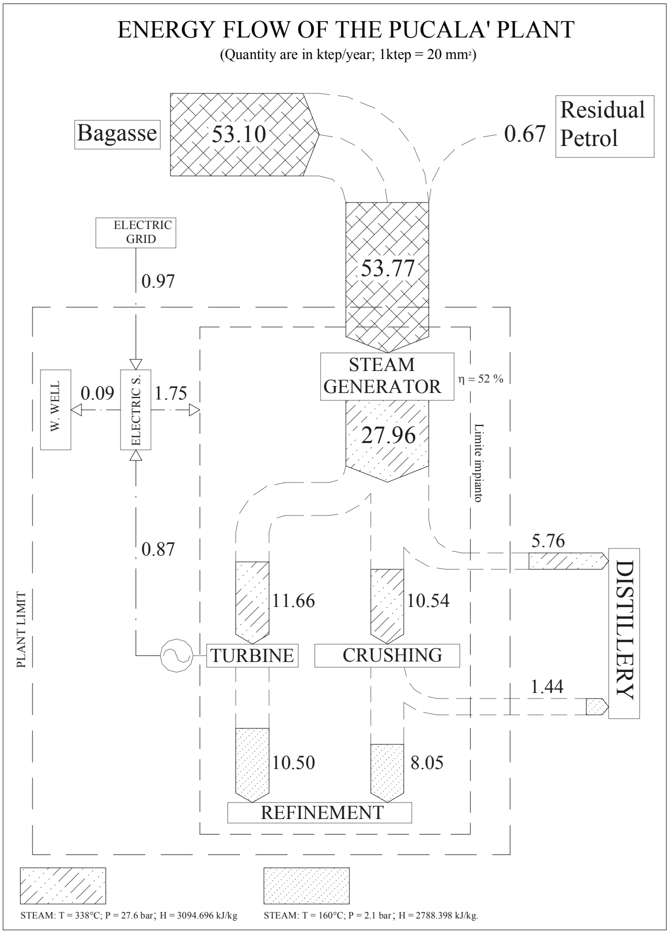

Figure 5. The energy flow of the Pucalà plant.

The production process of cane sugar shows that the mill has the main energy requirements. The flow of energy of the plant is showed in the figure 5.

The plant only uses the bagasse in order to contribute the satisfaction of energy needs. In the figure 6 the steam flow diagram are illustrated. Energy demand, and temperature and pressure of the necessary process steam are shown.

The energy balance at current conditions is:

- Energy from bagasse 53.77 ktep
- Energy from residual petrol 0.67 ktep
- Efficiency of the boiler 52%
- Process steam production 27.96 ktep (378,352 t)

- Steam to crushing 10.54 ktep (142,574 t)
- Steam to turbine 11.66 ktep (157,752 t)
- Steam to distillery 5.76 ktep (78,026 t)
- Electric energy use/year 1.84 ktep (21,339,200 kWh)
- Electric energy production/year 0.87 ktep (10,118,100 kWh)
- Electric energy **from** <u>the grid</u> 0.97 ktep (11,281,100 kWh)

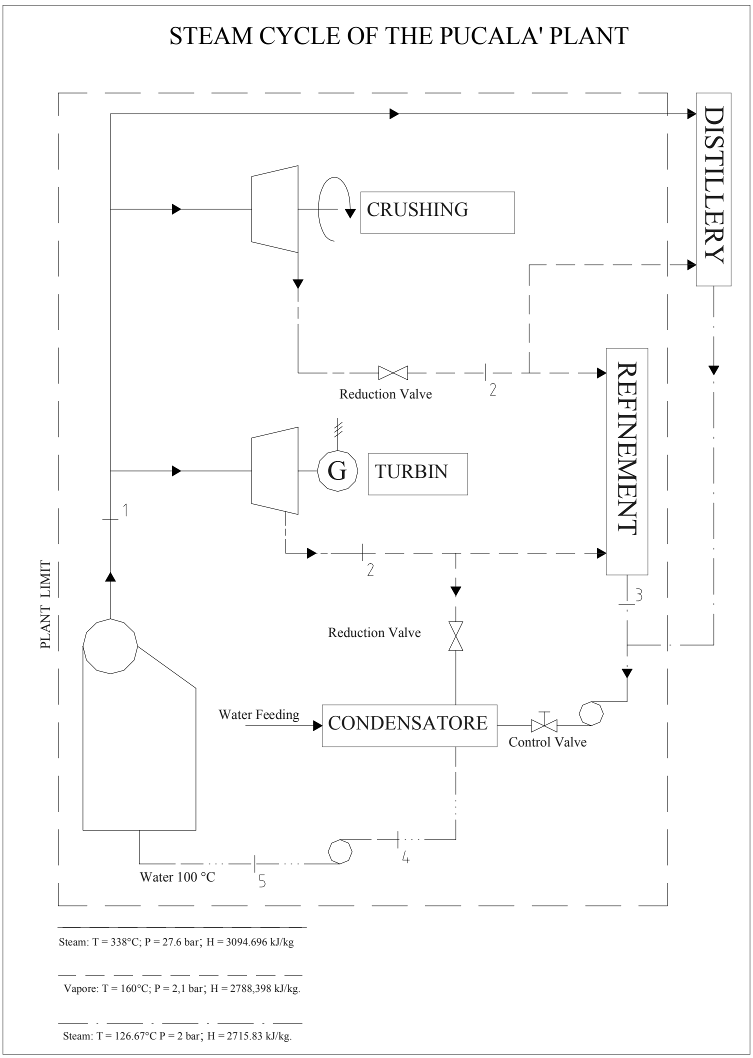

Figure 6. The steam cycle of Pucalà plant

5 Upgrading of the power plant

A sugar mill operating in the conditions previously described and analysed can be modified to obtain a major efficiency. The upgrading of the plant consists in the change of the old boiler with a boiler of current technology, similar at other mill plants in others countries (Brazil, Mauritius, Hawaii) coupling to condensing extraction steam turbine CEST. The process steam demands can be met using only a portion of the available steam with the CEST, extracting the steam at one or more points along the expansion path for meeting process needs. Steam that is not extracted continues to expand to sub-atmospheric pressures, thereby increasing the amount of electricity generated per unit of steam compared to the back-pressure turbine. The non-extracted steam is converted back to liquid water. The condensing steam turbine generally is employed to maximize electricity production. A typical Condensing Extraction Steam Turbine (CEST) operates at 4.0 to 6.0 MPa. These systems produce enough steam to supply a typical sugar factory and distillery and export 30 to 100 kWh of electricity per tonne of cane (kWh/tc) to other users or to the national grid. CEST systems represent the state-of-the-art for bagasse cogeneration in terms of mature technologies that are fully commercialized in the marketplace.

Under this operation condition the bagasse and the barbojo are used as a fuel. The bagasse and barbojo are drying with the exit combustion gases, first to begin the process, decreasing the humidity of the biomass around to 15-20%. The CV of the biomass will be about 17 MJ/kg.

The energy balance considering this upgrading is:

- Energy from bagasse 75.22 ktep
- Energy from barbojo 55.12 ktep
- Energy from fossil fuel 0.67 ktep (to ignition of the boiler)
- TOTAL Energy available 131 ktep (+77.23 ktep respect to current condition)
- Efficiency of the boiler 85%
- Process steam production 111.35 ktep
- Steam to grind 10.54 ktep
- Steam to turbine 95.05 ktep
- Steam to distillery 5.76 ktep
- Electric energy use/year 1.84 ktep
- Electric energy production/year 60.87 ktep
- Electric energy <u>to the grid</u> 55.99 ktep

6 Biomass Integrated Gasification Combined Cycle - BIGCC

Biomass integrated gasifier combined cycle (BIGCC) technology is a process with more high conversion efficiency. Further the development of gasification technologies is also important for a production of hydrogen form biomass. The system includes a pressurized circulating fluidized-bed gasifier, gas turbine, and steam turbine. Gasification involves transforming of biomass into a gas that can be used in a gas turbine, for example, to generate electricity. Gasification of biomass for use in a high efficiency gas turbine is a more advanced approach to bagasse cogeneration.

The steam drives a turbine-generator. Drying of the biomass is not usually required before combustion, but will improve overall efficiency if waste heat is utilised for drying. Steam turbines are designed as either "back-pressure" or "condensing" turbines.

Energy balance:

- Energy from bagasse 75.22 ktep
- Energy from barbojo 55.12 ktep
- Energy from fossil fuel 0.67 ktep (to ignition of the boiler)
- TOTAL Energy available 131 ktep (+77.23 ktep respect to current condition)
- Electric energy use/year 5.91 ktep (considering all internal use)
- Electric energy production/year 65.5 ktep
- Electric energy to the grid 59.59 ktep

7 Biomass Integrated Gasification Fuel Cell BIGFC

The previous considerations lead to the choice of a system that can be defined BIGFC (Biomass Integrated Gasification Fuel Cell), that produces hydrogen rich gas from sugar cane waste and uses that gas in fuel cells for power generation. The BIGFC plant will consist of an atmospheric pressure gasifier, warm cleanup and MCFC power generation unit, being the choices motivated by the following:

- no need of sophisticated feeding system and pressurised vessels;
- no need of high pressure (MCFC work at low pressure);
- noxious substances content well tolerated by MCFC and compressors.
- no need of additional gas coolers;
- no production of polluted water;
- noxious substances content well tolerated by MCFC and blowers.

A careful analysis of these reviews shows that there are still two main problems: a through systems approach to gasification facility and the gas cleaning. The Indirectly Heated Fluidized Bed Gasifier (IHFBG) - also defined Twin Fluidized Bed (TFB), or Fast Internally Circulated Fluidized Bed (FICFB) - represents the best gasification method for the purpose in the case of sugar cane biomass, because of:

- Independency of gas quality from fuel humidity content.;
- Separation of gasification and combustion processes;
- High calorific value of the gas, nitrogen free, with a little content of char and tars and a rich content of hydrogen;
- No need of pure oxygen;
- No moving part.

In a BIGFC system the analysis of the gasification process is an essential part, which allows, through the choice of a model, to be able to calculate the composition and the characteristics of the obtained gas. When insufficient data are available in order to obtain valid experimental relations, the experimental model is not suitable.

Energy balance:

- TOTAL Energy available 131 ktep
- Electric energy production/year 69.43 ktep (with 53% efficiency of MCFC)
- Electric energy use/year 6.10 ktep (considering all internal use)
- Electric energy to the grid 63.33 ktep

8 CONCLUSIONS

The use of bioenergy systems, specifically sugarcane plant, with modern technology contributes directly to a major electrical production with high efficiency. For the case of sugarcane plant in Chiclayo we can conclude that changing the old boiler for a modern boiler the production of electricity is bigger than requirements of the plant, then the surplus could be selling to the grid. The other possible technical solutions are the similar results, ensure the steam for the process, the electrical requirement and permit that the exceeding of electrical energy could be sell to the national grid. Sugarcane is an example of the potential for biomass modernisation on a larger scale. In developing countries grow and process sugarcane, generating substantial quantities of a fibrous biomass by-product (bagasse) that is used today at most mills as a fuel for combined heat and power (CHP) generation. CHP systems typically generate just enough electricity (a few megawatts at an average-sized facility) and process steam to meet the processing needs of the mill. The tops and leaves used as a fuel, would enable a CHP facility to operate year-round. With more efficient CHP systems and year-round operation, substantial amounts of electricity could be generated in excess of the mill's own requirements.

The emergence of new technologies to exploit valuable agricultural biomass residues has created new opportunities to diversify and expand sugarcane use, while capturing its environmental benefits as a renewable energy resource. As a result, the sugar industries in developing countries can increase profits and reduce risk by diversifying their production portfolios to include cane-based bio-energy products.

Is important to have into consideration that for a successful implementation of a bioenergy project, different institutional actors must be involved. These actors might include Central government, industries, non-governmental organisations, financing institutions, bilateral and multilateral organisations (World Bank, United Nations, etc). It is necessary to elaborate a coherent bioenergy policy, coordinated at a high level will more effectively promote and expand bioenergy than an uncoordinated set of disparate local activities. For example a central institution would support this coordination in many ways. A central coordinating institution could also develop and promulgate socioeconomic and environmental guidelines for bioenergy projects, including rules regarding access to project information and provisions for public participation.

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FINANCING PROJECTS RELATED TO ENVIRONMENTAL PROTECTION AND ENERGY EFFICIENCY

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Appropriate financing of programs and projects in the field of environmental protection, energy efficiency and renewable energy sources (RES) is one of major barriers to their realization. The existing financial sources, including state budget, local self-government budgets, commercial banks, international investment projects in environmental protection and international aid programs, are often insufficient or unattractive from the investors' viewpoint. Environmental Protection and Energy Efficiency Fund (EPEEF) is a relatively new player in Croatian investment market and it is basically first and only extra-budgetary fund dedicated to financing preparation, implementation and development of programs, projects and similar undertakings in the fields of preservation, sustainable use, protection and improvement of the environment, energy efficiency and use of RES.

1 Introduction

Appropriate financing of programs, projects and other measures in the field of environmental protection, energy efficiency and renewable energy sources (RES) is one of major barriers (apart from the legislative, administrative, institutional, informational, market and other barriers) to their realization. Those barriers are specially expressed in Central and Eastern European countries. The existing financial sources, including state budget, local self-government budgets, commercial banks, international investment projects in environmental protection and international aid programs, are often insufficient or unattractive from the investors' viewpoint.

Environmental Protection and Energy Efficiency Fund (EPEEF) is a relatively new player in Croatian investment market and it is basically first and only extra-budgetary fund dedicated to financing preparation, implementation and development of programs, projects and similar undertakings in the fields of preservation, sustainable use, protection and improvement of the environment, energy efficiency and use of RES in the Republic of Croatia.

Central and Eastern European countries have now many years of experience with such funds. First dedicated fund in the region was Polish National Fund for Environmental Protection and Water Management established in 1989. In 1991 it follows Czech and Slovak State Environmental Fund. Hungary and Bulgaria introduced similar funds in 1993. Primary goal of all mentioned funds is to conduct policies and strategies of environmental protection in home countries.

Experience of transitional countries showed that founding of such dedicated funds is most suitable solution in financing environmental protection during transition to market economy. It is also the most effective way to prevail and mitigate market and institutional barriers.

2 Environmental Protection and Energy Efficiency Fund

2.1 Establishment and Organization

Environmental Protection and Energy Efficiency Fund is a legal person vested with public authority in which, on behalf of the Republic of Croatia, founder's rights are exercised and duties discharged by the Government. EPEEF is established in 2003 according to the Act on Environmental Protection and Energy Efficiency Fund which finds its basis in Environmental Protection Act and Energy Act [1]. It became operational in the summer of 2004.

In its work EPEEF acts in accordance with number of laws and acts, such as: Environmental Protection Act, Energy Act and other laws concerning energy activities, National Environmental Protection Strategy, National Environmental Action Plan, National Energy Strategy, National Energy Programs, Stabilization and Association Agreement between Republic of Croatia and European Union and other international agreements.

2.2 Activities

Basically, EPEEF covers financing preparation, implementation and development of programs, projects and similar undertakings in two main areas:

- preservation, sustainable use, protection and improvement of the environment and
- energy efficiency and use of renewable energy sources.

In more details that includes:

- implementation of national energy programs,
- promotion of use of RES,
- sustainable building,
- cleaner transport,
- protection, preservation and improvement of air, soil, water and sea quality,
- moderation of climate change,
- waste management,

- cleaner production,
- protection and preservation of biological and landscape diversity,
- promotion of sustainable use of natural resources,
- sustainable development of rural areas,
- sustainable economic development,
- enhancement of the system of information, monitoring and assessment of the state of the environment,
- introduction of environment management system, and
- promotion of educational, research and development studies, programs, projects and other activities.

2.3 Financial Resources

Environmental Protection and Energy Efficiency Fund is an extra-budgetary fund whose financial resources are secured from charges levied in accordance with the Act on EPEEF (emission and waste charges), bilateral and multilateral cooperation, revenues from management of available monetary assets of the Fund, budgets of units of regional and local self-government, in accordance with jointly defined programs and grants. Projected revenue in 2006 is 1.003 billion HRK (or 136.5 million EUR).

The charges include:

1. Special environmental charge levied on motor vehicles. It applies as from March 1, 2004 and it is nowadays major financial resource of the EPEEF.
2. Charges levied on polluters of the environment (atmosphere), on:
   - SO_2 i NO_2 emissions (310 HRK/ton or 2.5 EUR/ton),
   - CO_2 emission (12 HRK/ton or 1.6 EUR/ton). The CO_2 emission charge is not yet introduced. The procedure for adoption of the Regulation is still undergoing and the Government of the Republic of Croatia will decide when to begin enforcing it.
3. Charges for burdening the environment with waste, on:
   - dumping municipal and non-hazardous industrial waste (12 HRK/ton or 1.6 EUR/ton). This charge applies as from June 1, 2004 only for industrial waste,
   - production of hazardous waste (100 HRK/ton or 13.7 EUR/ton).
4. Charge levied on environmental users e.g. for buildings or building complexes that are subject to procedure for assessment of their environmental impact. Not yet implemented.
5. Charges levied on packaging, started in 2005:

- recovery charge (according to material type and product unit),
- return charge (on packaging for drinks),
- subsidy charge (on packaging for drinks).

Total planed revenues in 2006 from the charges are shown in Table 1.

Table 1. Planed revenues in 2006.

	mill HRK
Financial assets revenues	1.20
CO_2 emission charge	53.30
NO_2 emission charge	5.00
SO_2 emission charge	11.00
Environmental users charges	67.00
Municipal waste charges and Non-hazardous Industrial waste charges	13.20
Hazardous Industrial waste charges	0.90
Special motor vehicles charge	200.00
Packaging charges	570.00
Waste tires recovery charge	25.00
Total revenue	**1003.60**

2.4 Planned investments

In the recent past the Government's and the Fund's priority was the waste management (particularly landfills remediation) but in the near future the importance of the energy efficiency will certainly grow (that can be seen from the four-year's Plan of EPEEF [2]). Allocation of the Fund's resources in 2006 related to environmental protection and energy efficiency is given in Figures 1 and 2.

Around 100 million HRK is allocated for energy efficiency, according to the percentages given on Figure 1, which includes: implementation of national energy programs, promotion of use of RES, sustainable building, cleaner transport, and other programs and projects.

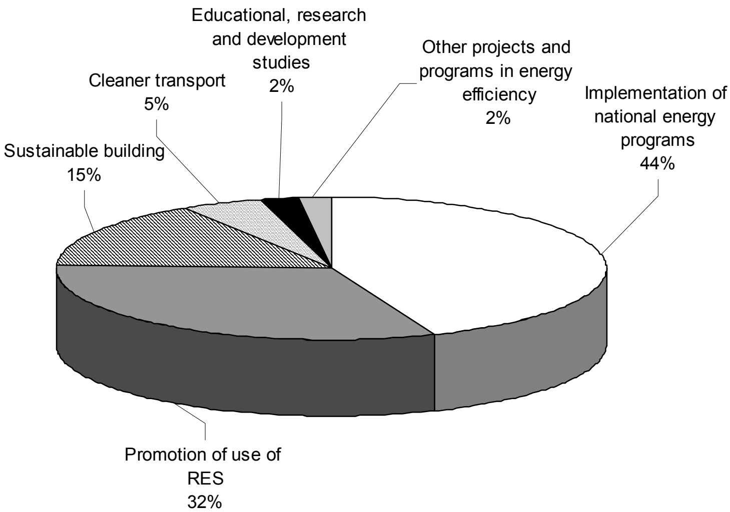

Figure 1. Planned investments in energy efficiency in 2006.

For the environmental protection in 2006 is allocated almost three times as much as for the energy efficiency. 298 million HRK will be invested in following areas: protection, preservation and improvement of air, soil, water and sea quality, moderation of climate change, waste management, cleaner manufacturing processes, protection and preservation of biological and landscape diversity, promotion of sustainable use of natural resources, sustainable development of rural areas, sustainable economic development, enhancement of the system of information, monitoring and assessment of the state of the environment, introduction of environment management system, promotion of educational, research and development studies, programs, projects and other activities (Figure 2).

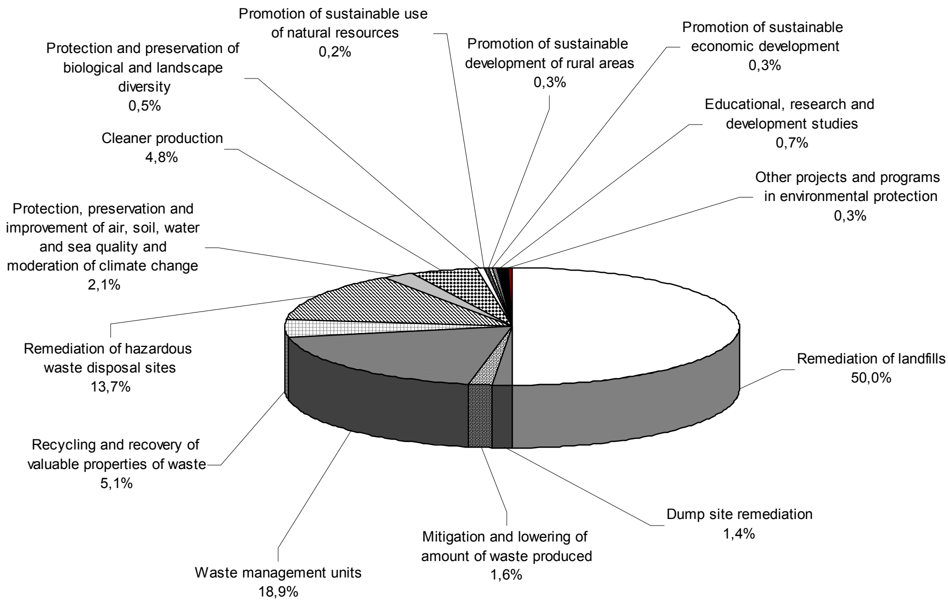

Figure 2. Planned investments in environmental protection in 2006.

Financial resources of the Fund shall be allocated to units of local self-government, legal and natural persons, which invest their own financial resources in programs and projects for which tenders are issued. Funds will be given on the basis of the public invitation of applications announced by the Fund. The resources shall be disbursed as "soft" loans (zero – interest rate), subsidies (of interest rate on commercial loans), grants and financial aid.

Fund shall not invite applications when, as a contractual party, it directly co-finances and participates in the realization of programs, projects and similar undertakings.

2.5 Recent Developments

Since the Fund has been operating for two and half years now, there are number of activities which are finished or are in progress. The majority of financial resources is disbursed for environmental protection, specially for the waste management:

- Two public invitations to units of local self-government for remediation of 163 landfills have finished; 1,300 million HRK will be disbursed in 3-5 years.
- Dump sites remediation, currently on 40 locations, for units of local self-government; 25.9 million HRK is planned.
- Remediation of hazardous waste disposal sites, on 9 locations of highly polluted environment - “black” spots, 545,000 HRK realized.
- Old tires recycling and energy use, 400,000 HRK.

- Garbage containers, 1.5 million HRK.
- Biodiversity, 332,000 HRK: island of Brač - Algae (*Caulerpe racemose*), island of Cres – White-headed vulture (*Griffon vulture*), etc.

First EPEEF's activity in the field of energy efficiency and RES was the public invitation for financing of energy audits and demonstrational activities in 2004. There were 37 energy audits in different companies executed by 9 energy auditors and 54 demonstrational activities of RES use and energy efficiency improvement. 2.2 million HRK was disbursed in total.
Other activities [3] included two public tenders for financing programs and projects of:

- energy efficiency (waste heat recovery, insulation, DSM, district heating systems, cogeneration, etc.), use of renewable energy sources (small wind, PV and solar thermal, small hydro, biomass, biofuel production, heat pumps, geothermal, hybrid system) and sustainable building (energy saving house, zero energy house, active and passive solar systems, insulation, micro - cogeneration, calorimeters, etc).
- reduction of emissions to the atmosphere (harmful emission reduction, GHG reduction, automatic measuring and monitoring of emissions, etc.) and cleaner production (clean technologies, waste and wastewater reduction, more efficient usage of raw materials, clean water and energy, reduction of emissions from the process, etc.).

In total, 34 projects of energy efficiency, use of renewable energy sources and sustainable building were accepted, for which 29 million HRK was allocated: 17.5 million HRK for energy efficiency (15.5 million HRK of loans, 0.4 million of subsidies, 1.6 million HRK of financial aid), renewable energy sources: 7.5 million HRK (2.3 million HRK of loans, 1.9 million of subsidies, 3.3 million HRK of financial aid), sustainable building: 3.8 million HRK: (1.7 million HRK of loans, 2.1 million HRK of financial aid).

The Fund is involved in number of national and international projects and programs. The most important development is the recent grant of the Global Environment Facility Trust Fund (GEF) and the World Bank: "Croatia – Renewable Energy Resources Project" in the amount of 5.5 million USD, for developing a rational policy framework for renewable energy [4]. This project has two main objectives: to support the market framework and other market conditions for renewable energy and to ensure an adequate and sustainable supply of potential projects through investment in the early stage of renewable energy project development. Use of biomass for energy production is priority but other RES systems (like wind or small hydro power plants) are not excluded. The Fund co-finances this project with additional 2.5 million USD in next 3-5 years.

The GEF grant and other EU funds will certainly help Croatia to fulfill the national goals for implementation of renewable energy, based on a clear understanding of the costs and technical issues related to financing and installing projects.

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AN ENERGY INTEGRATION TOOL FOR BATCH PROCESS

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Process integration is widely applied to continuous process. Among different methodologies, Pinch Analysis, with a thermodynamic basis is generally used due to it is easy implementation. The basic concepts of Pinch Analysis were therefore extended in this work to a batch process. The software developed, *BatchHeat*, highlights the energy inefficiencies in the process and thereby enables to set the scope for possible heat recovery, through direct heat exchange or storage. The *BatchHeat*, was applied to a case study as a first tool to get the targets for the heat exchanger network design. The results obtained show the enthalpy behaviour of the process and define an upper bound for direct heat transfer, thus suggesting different energy recovery projects. These alternatives were further compared and discussed.

1 Introduction

Batch process interest emerged since the 80's but mainly in the areas of simulation, design, and process stage scheduling to minimize operation unit investment and energy costs. However, process integration is also very important to optimise this type of process, though the results obtained by application of this methodology to batch processes have smaller energy savings, when compared with the results obtained for continuous processes [1]. Generally, batch process industrials are not prone to energy integration since they fear loosing control and flexibility. Furthermore, the costs related to yield and quality of the product are usually much more important than any energy savings from Process Integration.

Process integration, PI, is widely used in continuous processes [2]. Among different methodologies, Pinch Analysis, with a thermodynamic basis is widely used due to its easy implementation. The intermittent nature of batch processes imposes a three-dimensional data treatment in terms of enthalpy, temperature and time, which brings up high complexity, making manual treatment very difficult. The basic concepts of Pinch Analysis (PA) were therefore applied to batch processes [3, 4]. Different strategies can be

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applied depending on different scenarios [5, 6]: repeated batch when a cycle composed of various operations is repeated sequentially and single batch when the operations can not be considered to be repeated in time.

Literature review shows that software that deals with process integration is very recent. Softwares using Pinch analysis are Supertarget, and PinchExpress; Aspen Pinch; PRO_PI; HEXTRAN; PinchLeni, etc. To study batch processes, the available software concerning operation planning, scheduling, simulation and resources are for example: gBSS; BATCH; VirtECS Design; VirtECS Scheduler and Superbatch. The aim of this work was to develop a computational application, *BatchHeat*, applying Pinch Analysis to batch processes. This program is an initial tool for a global energy analysis, for continuous and batch processes, allowing the visualization of the enthalpy behaviour of the process through the Composite Curves construction.

2 BatchHeat Software

BatchHeat software presented in this work enables the user to determine the minimum energy consumption of continuous and batch processes, using different scenarios [7].

The first step to start working with *BatchHeat* is to select the type of process: continuous or batch. Afterwards, the user should fill a table with the characteristic variables for each stream:

- T_s - supply temperature – stream temperature before heat exchange.
- T_t - target temperature – desired stream temperature after heat exchange.
- $\dot{m}$ Cp - heat capacity of the stream, constant in the temperature and time interval considered.
- t_s - starting time.
- t_f - finishing time.
- ΔT_{min} – minimum temperature difference between hot and cold stream's temperature.

If heat transfer is internal, the temperature becomes time dependent and the user should split that stream in several intervals to reflect real conditions.

To make process integration study easier, *BatchHeat* allows the user to change previous data. This is very important to test operation-rescheduling hypotheses, to modify starting and finishing time of each operation, or to remove a stream included in the first analysis. *BatchHeat* could also be used to study the influence of different ΔT_{min} values on process energy integration.

Initially the program presents the easiest approach, using Time Average Model (TAM) presented by [6], which ignores the time and considers the process as a whole. Afterwards, *BatchHeat* generates a table, dividing the process at various time intervals and in terms of shifted temperatures (T'), calculated for hot or cold stream temperatures according to ΔT_{min} value. The table also shows the total enthalpy variation for each process stream. Hot streams are those requiring cooling and cold streams are those requiring heating.

After constructing the process enthalpy data table, the program presents infeasible the heat cascade [8]. As a first step the heat balance for a time period and between two temperature levels is given by:

$$Q_{kj} = (T_k - T_{k-1})\left(\sum_h \dot{m}_h Cp_h - \sum_c \dot{m}_c Cp_c\right)_{k,j} (t_j - t_{j-1}) \tag{1}$$

where k = [1, …, N] is the temperature level and j = [1, …, M] the time level.

To obtain the heat cascade, for each time period, along the temperature we calculate the cumulative enthalpy values for the different temperature levels:

$$I_{kj} = Q_{kj} + I_{k-1,j} \tag{2}$$

imposing the boundary condition:

$$I_{0j} = 0, \text{ for } j = [1,...,M] \tag{3}$$

If there is any negative I_{kj} value, the cascade is said to be infeasible since the heat must always flow from high temperatures. To overcome this situation, BatchHeat generates a feasible heat cascade, where the minimum consumption of hot utilities at each time interval is obtained by:

$$F_{0j} = -\left(\min\left(I_{0j},...,I_{kj},...,I_{Nj}\right)\right) \tag{4}$$

and the cumulative enthalpy values are recalculated for each temperature:

$$F_{kj} = Q_{kj} + F_{k-1,j} \tag{5}$$

From the calculated heat cascades for each time interval, the program enables the determination of the minimum heat consumption maximizing direct heat exchange and the visualization of the Grand Composite Curves for each time interval. These curves are a graphic representation of the cumulative enthalpy values, F_{kj}, obtained from the feasible heat cascades as a function of temperature.

Allowing heat flows to be time and temperature cascaded, it is possible to identify different possibilities for storing heat during the batch to be used in later time intervals. To obtain the energy storage potential for a single batch scenario, the program generates two separated cascades [7, 8]: one showing the available heat and the enthalpy needs at each temperature and the time interval. Comparing the heat required in one time interval with the available energy in the previous time interval, according to the temperature level, *BatchHeat* calculates the energy storage value.

Finally, program presents a resume table with the minimum consumption of hot and cold utilities for several scenarios: without integration and with integration (including or excluding the storage option).

3 Case Study

The present study is based on a case study of an industrial production of antibiotics. This multi-purpose plant is presently developing a relevant work of research and development, aiming an improvement in their production, considering also the energetic concerns.

In the first stage of this study, an analysis was performed to detect the zones with higher thermal energy consumptions since a major production cost in this type of factories is the electrical energy. The target at this stage is to identify the production steps where some investment on energy recovery would be justified. Thus, some material and energy balances were carried out to characterize in energy terms the process streams where energy integration might be applied. As in continuous processes, the most important step during the energy analysis is the extraction of stream data. Wrong data leads to misleading targets and missed opportunities.

The analysis of the collected data led to the conclusion that these energy consumptions vary in a relevant way, not only along the day but also along the week and the month, depending on the production schedule. Thus, after the graphs of steam consumptions in the production process have been analysed, the apparently most frequent and unfavourable profile was established. The fermentation zone is working all the time on a three shifts base, since each fermentation is working along cycles of several days.

Each fermentation batch starts with the feeding of the nutrient media to the fermenter followed by a sterilization cycle in which the first period is an heating period to raise the temperature inside the fermenter and the second period is a cooling period until the proper temperature for the inoculation is achieved. This final temperature is usually around room temperature. This cooling operation is carried out in two stages. In the first stage the cooling of fermentation medium is performed with cooling water from a cooling tower circuit whereas in the second stage a brine mixture of ethylene glycol / water is used until the fermentation temperature is achieved.

One should remind that in this production zone, steam is used not only as a utility but it is also directly injected inside the fermentation medium to exclude contaminations.

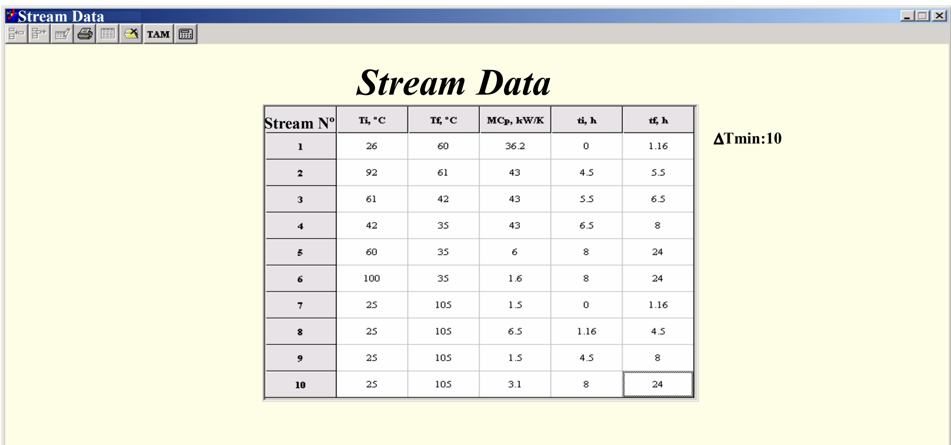
The Solvent Recovery Plant (Distillery) working, as average, 16 hours per day (2 shifts), uses 3.6 bar steam in several distillation units. Although the condensates of this steam may not be recovered directly to the system for safety reasons their enthalpy content may be recovered. The cooling water from cooling tower circuit satisfies this the cooling needs of the condensers in this process zone.

The global analysis identified other hot water and steam consumers, namely dryers, but, since the consumptions were not relevant, these units have not been considered in this study. Besides that, steam is also used in several points of the process such as sampling points. The resulting condensates were not accounted because they should be recovered directly to the steam boiler, reducing in this way the consumption of energy and of water to be treated.

In this work it was decided to study the enthalpy needs of only the Fermentation and Solvent Recovery zones, stressing four major process streams with interest for the energy integration study: heating of fermenter with steam (stream 1), cooling of fermenter (stream 2, 3 and 4); cooling of condensers with cooling water (stream 5) and cooling of the condensates from Solvent Recovery units (stream 6). Since the fermenter temperature during cooling is time dependent the original stream was splitted in three (stream 2 ,3 and 4) to reflect real conditions.

In the last stage of the sterilization process of the fermenter the heating should be carried out with direct steam injection and for this reason this step has not been included in the present work. In this study, streams related to the utilities system were also accounted since in this unit there is a preliminary heating of the total boiler feed water, since no condensates recovery is performed (stream 7, 8, 9 and 10).

Figure 1 presents the input stream data window, where hot and cold streams are characterized and a ΔT_{min} value of 10 ºC is imposed.

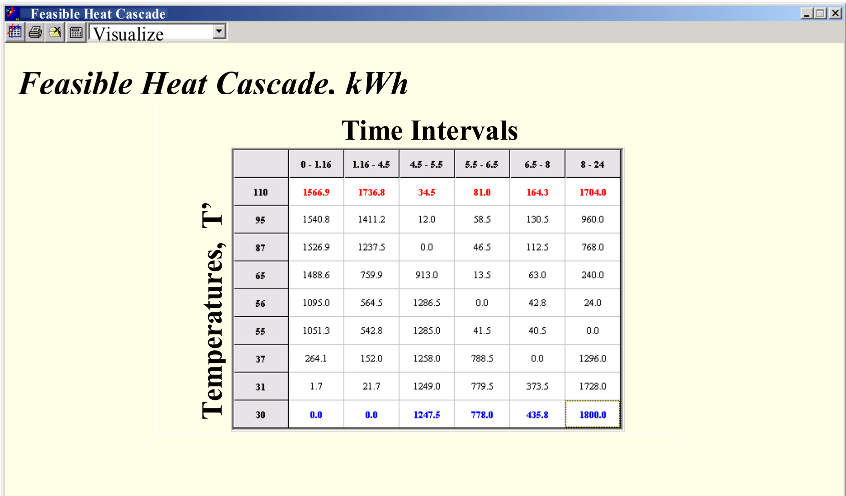


Stream Nº	Ti, °C	Tf, °C	MCp, kW/K	ti, h	tf, h
1	26	60	36.2	0	1.16
2	92	61	43	4.5	5.5
3	61	42	43	5.5	6.5
4	42	35	43	6.5	8
5	60	35	6	8	24
6	100	35	1.6	8	24
7	25	105	1.5	0	1.16
8	25	105	6.5	1.16	4.5
9	25	105	1.5	4.5	8
10	25	105	3.1	8	24

Figure 1. Input stream data window.

Heat cascade analysis is used to obtain the minimum hot and cold utilities consumption, requiring splitting the process streams in different time intervals. This model allows following accurately the enthalpy variation along time, showing the temperatures and time intervals, where it is necessary to use external heating and cooling. Applying this model to the case study data, we obtain the feasible heat cascades presented in Figure 2.

It should be noticed that the temperature axis is T`, which is a shifted temperature considering the ΔT_{min} approach imposed in this study. Hot streams are represented ΔTmin/2 colder and cold streams ΔTmin/2 hotter than they are in practice. These cascades show, for each time period, the pinch temperature point (temperature corresponding to a null enthalpy value), as well as the hot utility consumption (first line values) and cold utility consumption (last line values). Therefore, from Figure 2 one can conclude that the minimum consumption of hot and cold utility is 5 287.5 kWh and 4 261.3 kWh respectively.



Feasible Heat Cascade

Visualize

Feasible Heat Cascade. kWh

Time Intervals

Temperatures, T'	0 - 1.16	1.16 - 4.5	4.5 - 5.5	5.5 - 6.5	6.5 - 8	8 - 24
110	1566.9	1736.8	34.5	81.0	164.3	1704.0
95	1540.8	1411.2	12.0	58.5	130.5	960.0
87	1526.9	1237.5	0.0	46.5	112.5	768.0
65	1488.6	759.9	913.0	13.5	63.0	240.0
56	1095.0	564.5	1286.5	0.0	42.8	24.0
55	1051.3	542.8	1285.0	41.5	40.5	0.0
37	264.1	152.0	1258.0	788.5	0.0	1296.0
31	1.7	21.7	1249.0	779.5	373.5	1728.0
30	0.0	0.0	1247.5	778.0	435.8	1800.0

Figure 2. Feasible heat cascade for this case study.

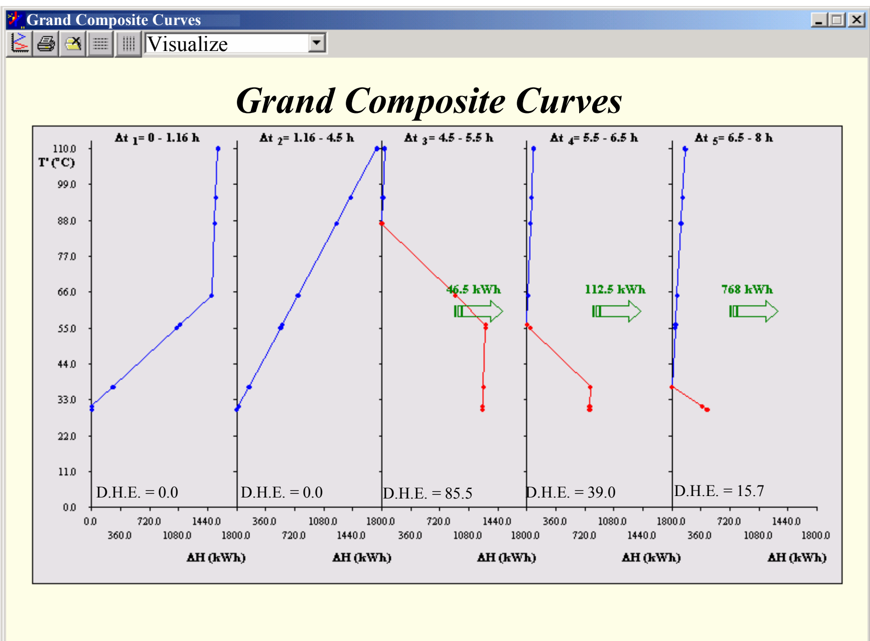


Figure 3. Grand Composite Curves for the first five time intervals.

The program also presents the Grand Composite Curves, for different time intervals, which were obtained by plotting the heat cascades presented previously. This cascade analysis allows identifying what streams may directly exchange heat, the enthalpy involved in these exchanges (D.H.E) as well as the storage potential (values above the arrow). Figure 3 and Figure 4 exhibits the Composite Curves obtained through BatchHeat for this case study.

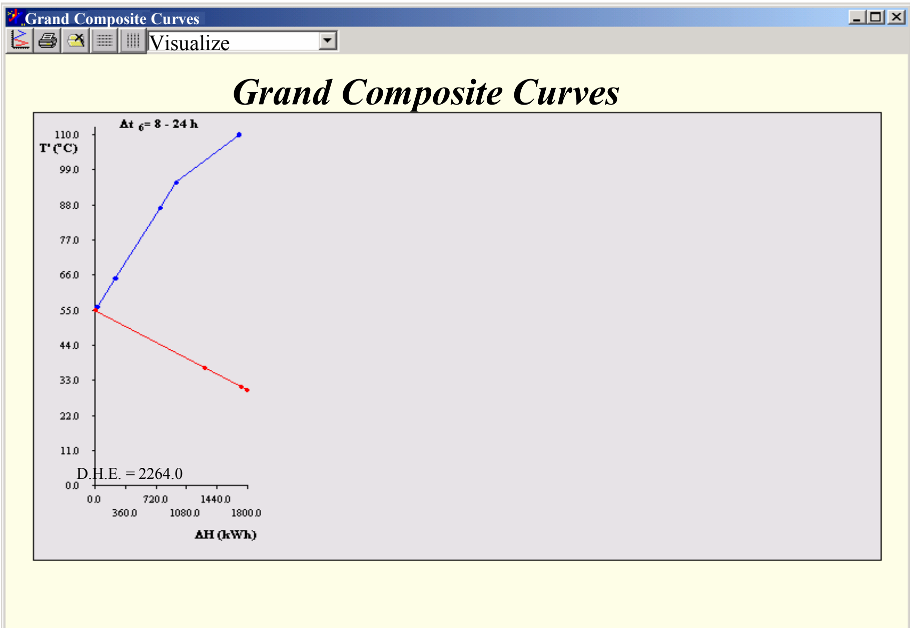


Figure 4. Grand Composite Curve for the sixth time interval.

From Figure 3 we can also calculate a storage potential value in a single batch scenario of 927 kWh which corresponds to a hot and cold utility consumption of 4 360.5 kWh and 3 334.3 kWh, respectively.

Table 1 summarizes the energy targets obtained for the different scenarios, showing that process integration without storage gives a scope to reduce the hot utility consumption by around 31 % and the cold utility by 36 %.

Table 1. Energy targets for this case study for three different integration scenarios

	Without Integration	With Integration	
		Without Storage	With Storage, in Single Batch
Total Storage, kWh	-	-	927.0
Hot Utility, kWh	7691.7	5287.5	4360.5
Cold Utility, kWh	6665.5	4261.3	3334.3

Based on Figure 3 and Figure 4 and considering the scenario of process integration without storage a comparison of the direct heat exchange opportunities, for the different time periods, was evaluated and presented in Table 2. This table enables the user to decide the viability of each heat exchange and to choose to carry them out or not. In the present case, and since the direct heat exchange of the sixth period between streams 5, 6 and 10 corresponds to 2 264 kWh and this enthalpy value is much higher than all the other ones we decided to carry out the study of different heat recovery projects for the last period of time (8 – 24 h). In this time period we have the distillery and the steam boiler working.

Table 2. Comparison of the direct heat exchange opportunities for the different time periods

Time Interval	Hot Stream	Cold Stream	D.H.E. (kWh)
3rd	2	9	85.5
4th	3	9	39.0
5th	4	9	15.7
6th	5,6	10	2264.0

To achieve the targets predicted by the program three projects of heat recovery were proposed. Project A and B use stream 5 (cooling of condensers) and stream 6 (cooling of the condensates) to preheat the total boiler feed water. The remaining energy needs are supplied by hot and cold utilities from the plant. Project C was created to reduce the number of heat exchangers leading to the cooling of the condensates with a single exchanger and using a cold utility.

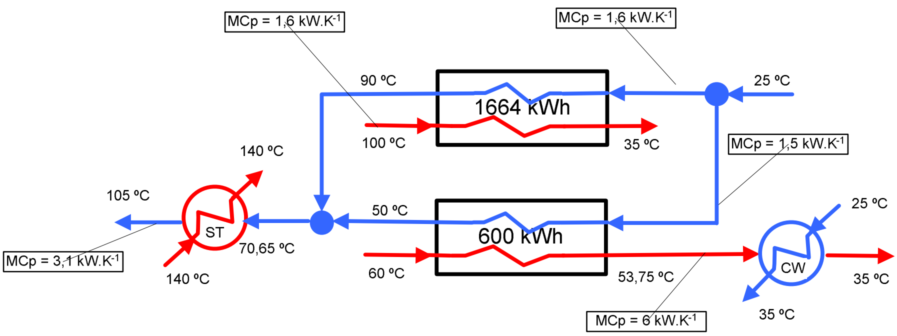


Figure 5. Project A - parallel scheme for direct heat integration of stream 5, 6 and 10.

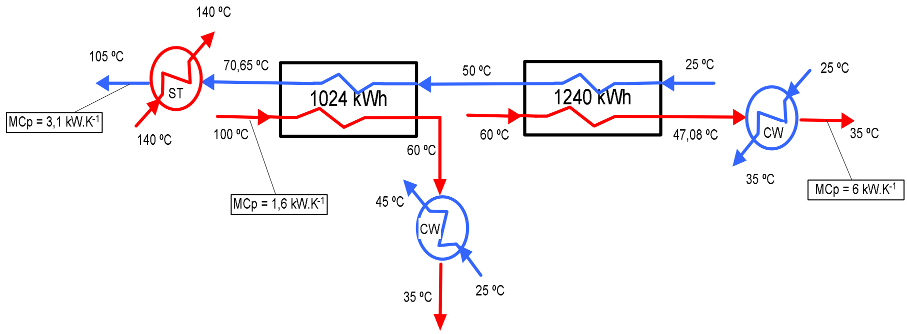


Figure 6. Project B - series scheme for direct heat integration of stream 5, 6 and 10.

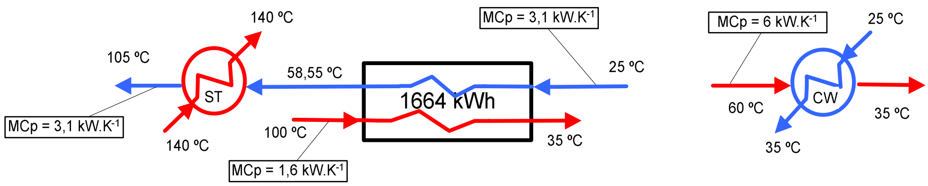


Figure 7. Project C - direct heat integration of stream 6 and 10.

Having set up the utility consumptions, the area and the number of heat exchangers were calculated. The comparison of the different energy recovery projects were performed by calculating for each scheme the total annualized cost. The investment for double pipe heat exchangers and shell and tube heat exchangers were obtained using the graphs presented in [9]. The costs of utilities were also estimated using the prices referred in [9]: 0.08\$/1000kg of cooling water and 4.4\$//1000kg of saturated steam. The investment was annualized for a five-year period and at a fixed rate of interest of 5% using the annualized factor:

$$Annualized\ capital\cos t = capital\ \cos t \times \frac{i(1+i)^n}{(1+i)^n - 1} \tag{6}$$

Table 3 presents the comparison of the three projects proposed, showing that A and B projects have smaller energy consumption since the direct heat exchange is maximized. Project C is a simpler one having higher utility consumption, but a smaller investment. In this case, and as the capital cost is not very relevant, project A seems to be the optimal choice because it presents the smaller total annual cost.

Table 3. Comparison of the three recovery heat projects.

Projects	D.H.E. (kWh)	Consumptions (kWh)		Annual Cost ($)			
				Capital	Utilities		**Total**
		Hot Utility	Cold Utility		Steam	Cold Water	
A	2 264	1 704	1 800	1 053.25	4 542.49	4 092.63	9 688.37
B	2 264	1 704	1 800	1 298.08	4 542.49	4 092.63	9 933.20
C	1 664	2 304	2 400	789.93	6 141.96	5 456.84	12 388.73

4 Conclusion

Pinch analysis advantage is expressed by simple and easy application to real situations, continuous or batch processes, through suggestion of process modifications in order to reduce heat consumption and effluents.

Batch processes having a three-dimensional dependency of enthalpy, temperature and time, make the application of Pinch Analysis to this type of process very complex. *BatchHeat* software, using automatic calculation allows a global process view and enables to identify exceeding and deficit enthalpy areas and therefore to obtain Heat Exchanger networks corresponding to the minimum heat consumption. The Cascade Analysis was applied to a case study to highlight the inefficiencies in the process and thereby to set the scope for three possible heat recovery projects. These alternatives were afterwards compared in term of the total annual cost. *BatchHeat* is therefore an initial tool for a global energy analysis of all productive process, including continuous and discontinuous process and utility system.

Nomenclature

Cp – specific heat capacity, kJ/kg K
F – heat flow for the feasible heat cascade, kWh
I – heat flow for the feasible heat cascade, kWh
$\dot{m}$ – mass flow rate, kg/s
Q – heat load for a batch process, kWh
T – absolute temperature, K
t – time, s

Subscripts

j – time level
k – temperature level
min – minimum
h – hot
c – cold

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THE EFFECT OF WATER OBJECTS ON SUMMER MICROCLIMATE IN DRY REGIONS

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Air/water heat exchange can be used for natural cooling of open spaces and building interior. Potential of open static and dynamic water objects for lowering air temperature is analysed through simplified calculations. How building and open space features influence natural cooling with water is shown on examples. Appropriate inclusion of open water objects in building ensembles can improve microclimatic conditions and thus summer thermal comfort.

1. Summer Energy Efficiency of Buildings

Beside well-known mechanisms of winter energy efficiency of buildings, summer energy efficiency has also become important topic for a number of years. Rise of standard of living has brought the significant increase in use of air conditioning devices in southern European regions, while unusually hot summers in the last few years had the same consequence in some parts of central Europe. With the aim not to lose, by use of air conditioning equipment, the funds saved by winter efficiency measures, to decrease emission of greenhouse gases and to avoid adverse effects of air conditioning devices on human psycho-physiological comfort, a number of natural cooling techniques in buildings and adjacent open spaces have been developed.

1.1. *Natural Cooling Techniques*

The ways of cooling buildings without use of artificial air-conditioning are of course not new, but well known for centuries. New, sometimes complex, and often simply neglected and forgotten is the application of these cooling techniques in contemporary buildings.

1.1.1. *Natural cooling of exterior place*

Important role in natural cooling of buildings have cooling measures in the exterior, open spaces, next to the building. The aim of these measures is to lower the load on, and to contribute to, natural cooling of the interior, and to improve thermal comfort in open spaces.

Natural cooling measures in exterior places can be particularly interesting in hotel industry and restaurants (open terraces), same as on fairgrounds, urban open spaces (city centres), etc. Basic means for exterior natural cooling are [1]:

- Plants;
- Shading;

- Ventilation;
- Use of water;
- Thermal inertia of the ground;
- Systems of long-wave radiation;
- Filter organization;
- Strategy of use schedule, zone definition, psychological aspects, etc.

2. Use of Water for Natural Cooling

To be able to use water for natural cooling of open space and building interior, one has to be familiar with heat transfer processes on open water surface [2]. In principle, these are:

- Radiation from the sun.
- Long-wave radiation from water to night sky.
- Direct heat transfer air/water (transfer of sensible heat).
- Evaporative heat transfer.
- Advective heat transfer (currents, vertical convection, turbulence).

There are also secondary processes that can have effect on thermal state of an open water mass:

- Chemical/biological processes.
- Thermal processes in earth's interior and hydrothermal activity.
- Current friction.
- Radioactivity.

Mentioned processes can happen in any open water mass, though secondary processes are more present in natural water masses such as rivers, lakes, seas and oceans. Through all these processes the heat is either transferred to, or from, water mass. Secondary processes are always source of heat.

2.1. *Natural Cooling of Air by Means of Artificial Water Objects*

If the purpose of inclusion of artificial water objects in a building ensemble is to cool air, few principles have to be observed to be able to fully exploit positive characteristics of water mass.

For the purpose of this paper we have introduced two types of artificial water objects:

- "Static" such as (swimming) pools, basins, small artificial lakes, etc.
- "Dynamic" such as waterfalls, cascades, fountains, canals, water curtains, etc.

Functioning of these types is based on two physical processes:

- Sensible heat exchange, i.e. direct heat transfer from air to water.
- Latent heat exchange, i.e. evaporation.

2.1.1. *"Static" Water Objects*

Thermal inertia, i.e. substantial specific heat of "static" water objects, is its major property that makes it convenient for cooling of air. The air with lower, acceptable temperature, around and in the building can be achieved by means of heat transfer from air to water. For this to happen, basic assumption of water being cooler than air in the process of heat transfer has to be fulfilled:

$$T_{\text{water}} < T_{\text{air}}. \tag{1}$$

This temperature difference ΔT should be maintained during whole cooling period. To prevent warming up of water as much as possible, there are few measures that should be applied:

- Blocking radiation from the sun to water mass during day (shading), Figure 1.
- Enabling heat transfer from water to the ground (no thermal insulation).
- Encouraging long wave radiation from water surface to sky during night (no shading), Figure 2.

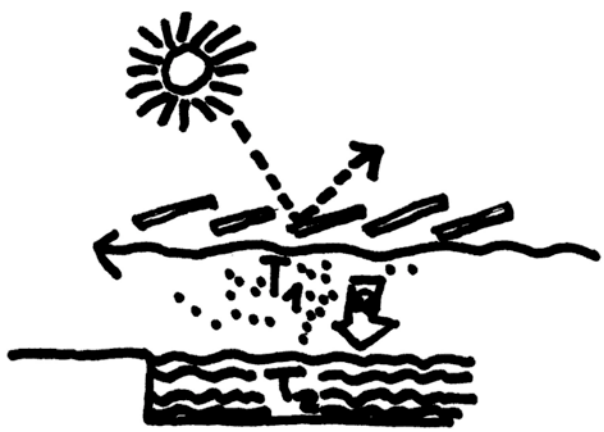

Figure 1. Day-time regime of water object regarding cooling of air.

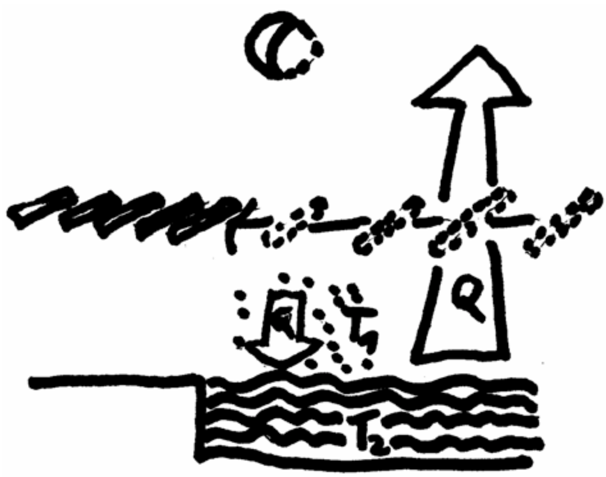

Figure 2. Night-time regime of water object regarding cooling of air.

- Stimulating evaporation during night.

Evaporation from "static" water objects should be kept low during day, so that cooled air still has acceptable humidity.

2.1.2. *"Dynamic" Water Objects*

Cooling of air through increased evaporation is characteristics of dynamic water objects and two measures are necessary for achieving favourable microclimatic conditions and continuous evaporation process:

- Combination with ventilation to control relative air humidity.
- Shading of "dynamic" water objects to achieve lower air temperature.

"Dynamic" water objects can function in closed cycles maintained by electric pumps powered with photovoltaic panels.

3. Basic Equations for Heat Exchange Air/Water

To be able to estimate the essential parameter of the cooling process, i.e. temperature difference between the air coming to and air leaving a water object, it is necessary to know heat fluxes from air to water. Sensible heat flux j_{sens} at different temperatures of air T_{air} and of water surface T_{surf} can be approximated from [3] by:

$$j_{\mathrm{sens}} = k_{\mathrm{T}}^{\mathrm{air}} \rho_{\mathrm{air}} c_{\mathrm{p}}^{\mathrm{air}} \left(T_{\mathrm{air}} - T_{\mathrm{surf}} \right), \qquad (2)$$

where ρ_{air} denotes air density, c_p^{air} specific heat of air and k_T^{air} transfer velocities of heat in air.

Phase change of water from liquid to gaseous phase requires latent heat of evaporation $L_e = 2.344 \cdot 10^{-6}$ J kg^{-1} from air/water interface. Relative air humidity h near water surface is driving force of latent heat flux j_{lat} that can be approximately determined from [3] by:

$$j_{lat} = - k_q^{air} L_e c_q (1 - h), \tag{3}$$

where L_e denotes latent heat of evaporation, c_q saturation vapour density and k_q^{air} transfer velocities of water vapour in air.

Temperature difference of water due to evaporation ΔT, in conditions without heat exchange with the surroundings, is given by the relation between heat loss of water necessary for evaporation, ΔQ and specific heat of water c and mass of water m from [4]:

$$\Delta T = \frac{\Delta Q}{c\,m}. \tag{4}$$

According to Eq. (4), temperature difference of 200 g of water, as consequence of evaporation of 0.5 g water, is equal to ΔT = 1.35 °C. In Table 1 is shown previous experience [1] regarding capability of water evaporation for cooling of air.

Table 1. Cooling of air through water evaporation.

Air	Temperature T (°C)	Relative humidity h (%)
Input	35	40
Output	26.5	80
Heat transfer from air for evaporation of 1 g water q = 2428 J Upper limit of psycho-physiological comfort h = 80 %		

4. Analysis of Natural Cooling Air/Water on Two Examples

Two real buildings with nearby water objects are discussed with respect to possibility for natural cooling using water as heat sink. First building with open swimming pool represents example of use of “static” water object, while second one with the flowing/falling water canal and partly sprinkling water represents example of use of “dynamic” water object.

4.1. *Swimming Pool near the Building*

A villa, situated on the east coast of the Adriatic Sea enjoys Mediterranean climate [5], with high summer temperatures and low relative air humidity. An open swimming pool is placed next to the south side of the building, Figure 3.

Figure 3. Villa with the swimming pool, cooling measures

Although a swimming pool positively influences summer microclimatic conditions through water evaporation, it cannot be fully exploited for cooling purposes due to its function. Water intended for cooling of air should be at lowest possible temperature to retain its thermal capacity during whole day period. For this reason it should by all means protected from sun radiation, through, e.g. reflective canopy, Figure 3.

If the purpose of natural water cooling is also to cool interior spaces, the path of the cooled air into the building should be enabled, same as stimulation of its circulation by means of convenient arrangement of interior and exterior spaces aiming at triggering of physical process of warm air rising and replacing it with cooled outside air.

4.2. *Water Canal and Small Waterfall near the Building*

A small traditional water mill is situated in a continental region of southeast Europe [6]. An open canal delivers water to the mill, superfluous water being dissipated as small waterfall. Due to the extremely hot summers in recent years, mentioned region experiences high thermal stress during summer months. For this reason, it is useful to consider cooling processes in this example, as model for more artificial building situations, Figure 4.

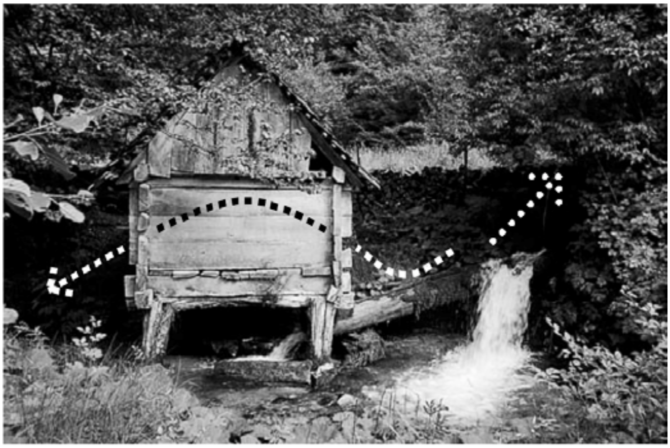

Figure 4. Water mill as a model for urban applications.

Flowing of water is essential difference between “static” and “dynamic” water object. Evaporation rate and heat loss rate to the ground of flowing water is higher than with the “static” water, so that lower water temperature is easier retained. Basic principle of protecting the water object from sun radiation was accidentally observed in this case, where main process of cooling of air proceeds through evaporation. If penetration of cooled air in the building were desired, additional provisions would have to be made in this instance.

5. Requirements for Practice and Future Research

Efficiency of natural cooling techniques fundamentally depends on their purposeful spatial integration with the buildings and open spaces, because they use and enhance natural processes already present in the in the environment, Figure 5.

For this reason, city planers and architects should be familiar with the principles of natural mechanisms described in the paper to be able to include them properly in urban or architectural solutions, Figure 6. Natural cooling of air by means of open water objects should be carefully planned, because of the rise of relative air humidity that can have adverse effect on psycho-physiological comfort [7]. Planers should indeed be aware of the whole year use cycle of building and open spaces and plan the use regimes of water objects, or alternatively empty water containers, all year round.

Existing water objects near buildings, e.g. swimming pools or decorative basins and lakes, can help alleviate summer thermal stress. However, they are predominantly not suitable to be fully exploited for purpose of cooling of air, due to their primary function, or to the inconvenient spatial relation to the building.

Beside effect of cooling, use of water in the summer environment also has other advantages. Visual and aural characteristics of water positively influence psychological well-being.

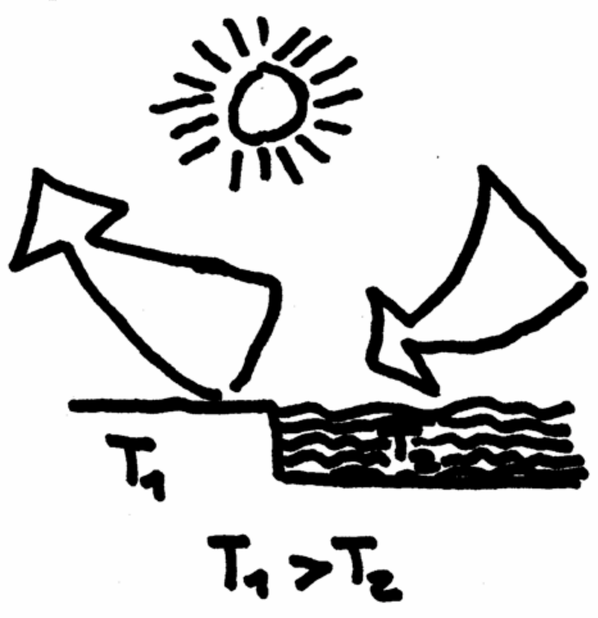

Figure 5. Natural air movement near the water mass during the day.

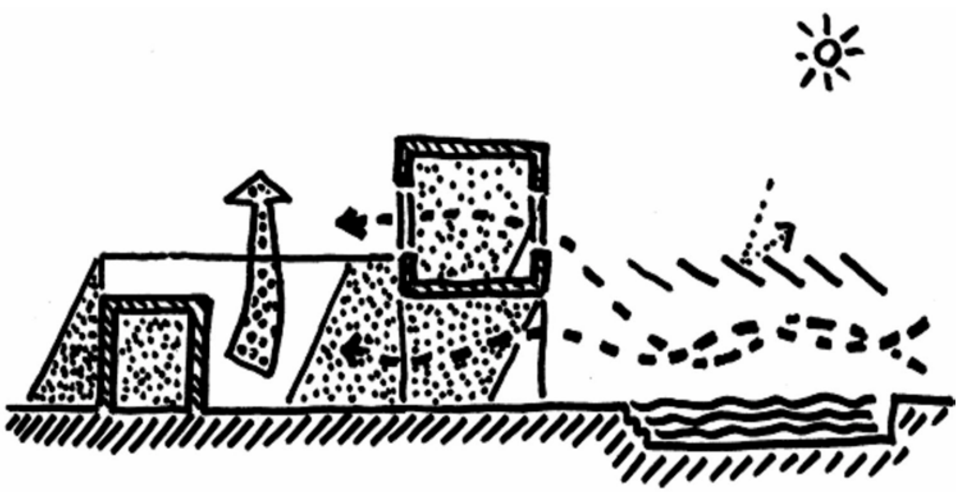

Figure 6. Integration of design with the natural cooling solutions.

5.1. *Future Research*

If natural cooling techniques are to be convincing replacement for standard air-conditioning and suitable for planning, their parameters have to be determined at least approximately. In this sense, next step of research in the field of natural cooling of air by means of water would be determination of parameters that influence effect of cooling in both described models. Although various studies already exist, it would still be optimal to conduct a case study with the foreseen duration of parameter monitoring of 30 uninterrupted days during summer period, due to specific microclimatic conditions in different regions and various building and open space solutions and configurations.

Nomenclature

T_{water}	water temperature;	L_e	latent heat of evaporation;
T_{air}	air temperature;	h	relative air humidity;
ΔT	temperature difference;	j_{lat}	latent heat flux;
j_{sens}	sensible heat flux;	c_q	saturation vapour density;
T_{surf}	water surface temperature;	k_q^{air}	transfer velocities of water vapour in air;
ρ_{air}	air density;	ΔQ	heat loss;
c_p^{air}	specific heat of air;	c	specific heat of water;
k_T^{air}	transfer velocities of heat in air;	m	mass of water;

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ENERGY COGENERATION

FIRST MICRO COMBINED HEAT AND POWER SYSTEM IN A SWIMMING POOL IN PORTUGAL: TECHNO-ECONOMICAL EVALUATION AND POLICY FRAMEWORK

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A micro combined heat and power (MCHP) system supplied by propane was studied and implemented in a swimming pool. The study starts with the electric energy production Portuguese policy framework and energy consumption analyses. The selected MCHP system has the power of 22 kWe and 45 kWth in order to fulfill with the limitations imposed by policy framework. The electrical power generated is, intentionally, higher than the requirements to supply the exceeding energy to the network. In the economic evaluation we studied and simulate different situations of buying and selling electrical energy based on the Portuguese tariff. The system reveals to be economic viable for the company as well as for the host. This project is the first of the kind implemented in Portugal and represent a step forward for the country energy market.

1 Introduction

Combined heat and power (CHP), also known as cogeneration, means that both electrical and thermal energy are generated simultaneously. The benefit is the overall efficiency, which can be as much as 85–90% [1]. If only electricity is produced, an efficiency of only 40–45% can be achieved. When compared to conventional thermo-power generation, it ensures lowest energy consumption and reduces pollutants emissions [2]. Additionally, cogeneration plants could serve electricity markets with lower investments in the transmission and distribution grids and with lower energy losses during transmission [3]. Thus, CHP can be regarded as an efficient way to produce energy. Conventionally, CHP plants have been large-sized, centralized units. Steam and heat produced by these plants can be utilized in industrial processes and district heating, provided that the steam temperature is high enough. A new trend is towards distributed CHP, which means that the energy production unit is situated close to energy consumers and large-sized, centralized units are substituted by smaller ones. If the electrical power produced by the plant is less than 1 MW or 50 kW, the terms small-scale distributed CHP and micro-CHP are used, respectively [4]. It is expected that every residential boiler would be replaced by a cogeneration unit in the near future resulting in an enormous potential. Furthermore every swimming pool, rest home, apartment, school, etc. will be suitable for a small-scale or micro cogeneration unit [5].

The relevant competing technologies in this regard are internal combustion engines, micro-turbines, Stirling engines, and fuel cells. In the smallest size, fuel cells and Stirling engines are regarded as the most applicable technologies being the internal combustion engines and turbines applicable in the remaining cases.

Regarding the independent electric energy production policy framework, the entity "producer-consumer" was created by the Decree-Law 68/2002 allowing the production of electric energy in low tension. This paper shows the first application in Portugal of this law.

2 Policy framework

In Portugal, the electric sector has been the object of profound changes since the end of the 1980's, when the production and distribution of electric energy was opened up to private initiative through Decree-Law 449/88. In 1991, the restructuring of this sector continued its evolution with Decree-Law 99/91, which established the general principles of the legal regime for the activities of production, transmission and distribution of electric energy.

The bases and principles of the organization and functioning of the National Electric System, in its actual legislative framework, were set down in Decree-Law 182/95, of 27th July, with the subsequent wording given by Decree-Laws 56/97 of 14th March, 24/95 of 24th January, and 198/2000 of 24th August.

The principals established by this legislative package were developed by Decree-Laws 183/95, 184/95, 185/95 and 187/95 of 27th July, which approved the general legal regimes of production, distribution and transmission of electric energy.

Directive 96/92/CE of the European Parliament and the Council resulted in widespread changes to the legal and organizational panorama of the electric sector. The National Electric System (SEN) has been subject to many alterations. Based on the above-mentioned legal instruments, specific regulations were produced, and revised in September 2001, of which special mention should be made to the Tariff Code, the Commercial Relations Code, the Dispatch Code and the Access to the public grid and to the Interconnections Code.

In 2002, the entity "producer-consumer" was created by the Decree-Law 68/2002 allowing the production of electric energy in low tension. At least 50% of the produced electric energy must be self-consumed. The maximum power which can be delivered to the grid is 150 kWe [6].

The remuneration for the electric energy delivered to the grid is defined by the following equation [7]:

$$VRD_m = VRD(BTE)_m + C_t \times EEC_m \times IPC_{dez} \div IPC_{ref}\,, \tag{1}$$

where:

- VRD_m is the monthly remuneration;

- $VRD(BTE)_m$ – is the electric energy value delivered to the network by the installation in SLV (special low voltage) tariff excluding the fixed monthly charge and the power fee;
- C_t – used technology coefficient, varying from 0.01 €/kWh (Otto engine cycle) to 0.20 €/kWh (photovoltaic and fuel cells);
- EEC_m – electric energy delivered to the network;
- IPC_{dez} – consumer prices index in December of the last year (equal to 107, December 2005);
- IPC_{ref} – reference consumer prices index (equal to 98.1, December 2001).

3 Energetic Analysis

In order to evaluate the potential energy saving of a MCHP system it is important to compare the primary energy used by the MCHP with that used in conventional systems that supply the electric and thermal demands of the user; to this aim it is important to underline that the energetic analysis, and then the efficiencies evaluation, must be defined with reference to the energy actually used by the end-user and not with reference to a control volume that includes the system only.

The existing heating system is composed by a boiler supplied by propane and electric energy is supplied by the public grid. The annual consumption is showed in the Figure 1.

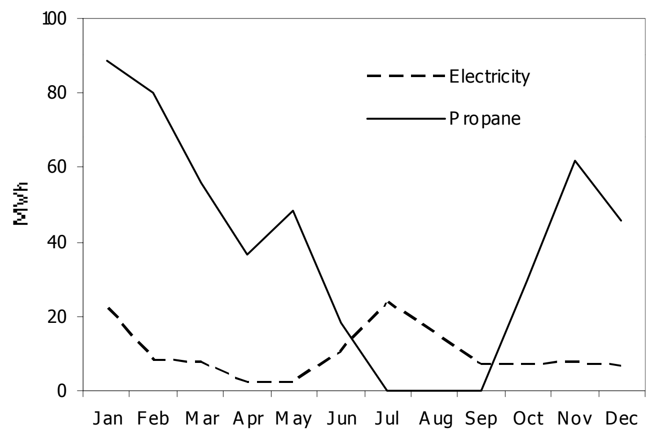

Figure 1. Energy consumption of the conventional system.

The average value of electric energy consumption is about 9.000 kWh_e per month. It is possible to verify that there is no consumption of propane during three months (July, August and September) which corresponds to the period where the swimming pool is closed. The average value of thermal energy consumption per month is about 52.000 kWh_{th}.

In order to have a better idea of the real energy consumption measurements were made in typical the winter and summer days. These measurements are showed in the Figures 2 and 3.

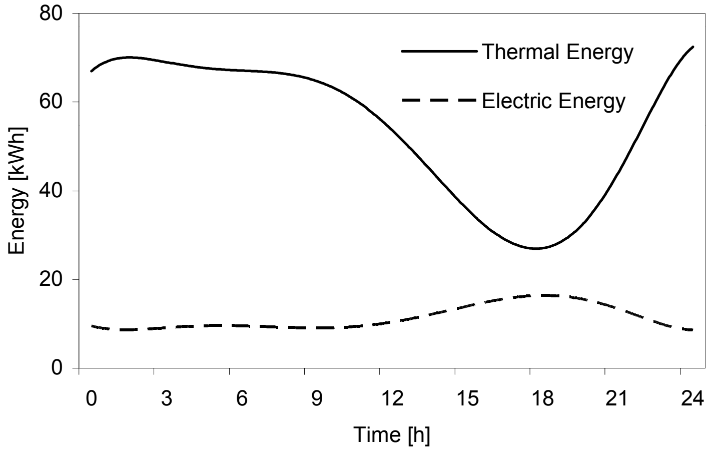

Figure 2. Energy consumption on a typical winter day.

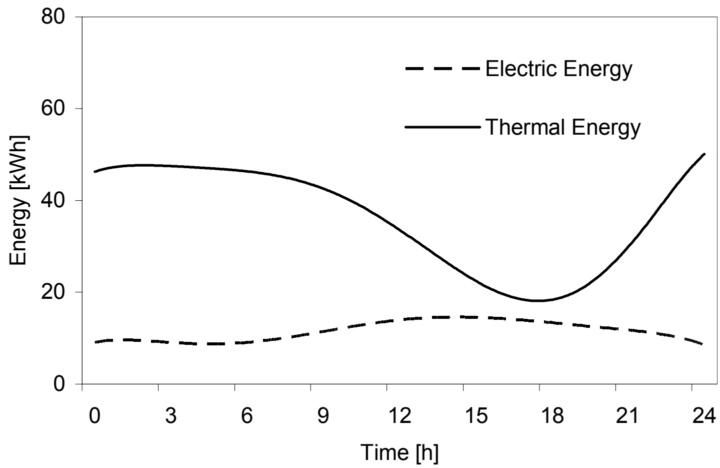

Figure 3. Energy consumption in a typical summer day.

It's possible to verify that the electric power consumption ranges about 10 to 15 kW_e. The thermal power consumption ranges about 20 to 70 kW_{th}. The boiler efficiency is 78%.

4 System dimensioning

The competing technologies in this regard are internal combustion engines (ICE), micro-turbines, Stirling engines, and fuel cells. The last two technologies were not considered because of the high investment costs. Between the engines and micro-turbines the features are very similar. An ICE was chosen essentially because it high electrical power/heat flow ratio [5,8].

According with the power consumption and the limitations imposed by the Decree-Law 68/2002, the selected MCHP system has the following characteristics:

1. Electric power: 22 kWe;
2. Thermal power: 45.5 kWth;
3. Fuel consumption: 77.5 kWc;
4. Efficiency: 87%.

5 Implementation

The introduction of the MCHP system in the swimming pool facility promotes some changes that must be made. Figure 4 shows the energy flux between the MCHP system, swimming pool and the electrical company.

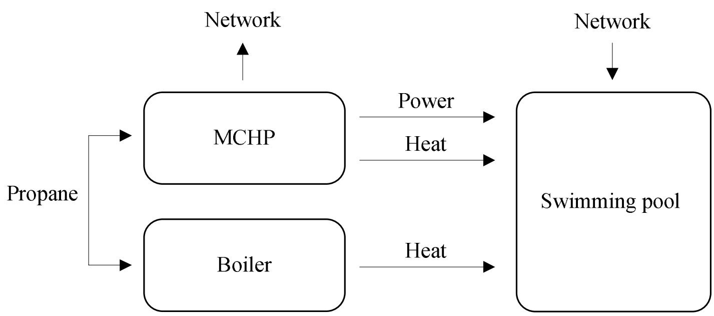

Figure 4. Energy flux in the swimming pool.

The MCHP system produces heat and power that is supplied to the swimming pool facility. The excess of electric energy is supplied to the public grid. For security reasons the electric connection to the public grid was maintained which allows the use an asynchronous generator. The electric installation was made like is showed in Figure 5.

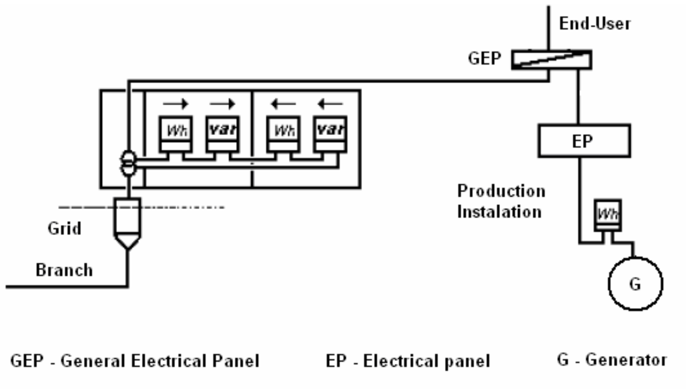

Figure 5. Electric installation.

The installed power is 50 kVA, therefore according to the Portuguese electrical company we are in the special low voltage (SLV) tariff, which means that the reactive energy must be measured. The generator produces electric energy that is measured in a meter, connected to an electrical panel for protection. Two meters serial coupled measure the electric energy delivered and acquired to the network. These two systems are linked to a general electrical panel, from where the end-user is supplied.

6 Economic evaluation

In order to find the best tariff of buying and selling electric energy to and for the public grid some possible scenarios are study.

The old electric installation was supplied in normal low voltage (NLV) and new electric installation is supplied in special low voltage (SLV). There are two different situations on the SLV tariff: medium (SLV-MU) and long utilizations (SLV-LU). In both cases the active energy is daily scheduled charged into three different values. The interested reader can consult the reference [9] for further information.

The peak active energy has a high cost when considering medium utilizations, whereas considering long utilizations is the power in peak hours that has a high cost. The reactive energy is only charged in the off-peak hours and if the value is higher than 40% of the active energy consumption. This situation never happens in the considered installation, therefore this term is null.

Before simulating the annual performance of the MCHP system a critical situation must be solved. When the swimming pool is closed no thermal energy is consumed, therefore two cases are studied:

- Full stop (Table 1);
- Running only in peak hours (Table 2).

Table 1. MCHP full stop economical evaluation.

Billing element		**Producer (€)**	**Consumer (€)**
Active energy	Peak	148.2	761.4
	Standard	258.8	
	Off peak	112.5	
Power	Peak hours	140.1	0.0
	Fee	61.5	
Fixed monthly charge		18.6	91.6
Total		**740**	**853**

Table 2. Economic evaluation of the MCHP running only in peak hours.

Billing element		**Producer (€)**	**Consumer (€)**	**Network (€)**
Active energy	Peak	0	761.4	197
	Standard	259		0.0
	Off peak	112		0.0
Power	Peak hours	0	-	62
	Fee	62	-	0.0
Fixed monthly charge		18.6	91.6	0.0
Propane		428	-	12
Total		**879.6**	**853**	**271**

From Tables 1 and 2 it is possible to conclude that the MCHP system should run in peak hours whenever the swimming pool is closed.

The new energetic condition was simulated and the following graphics were obtained.

Figure 6 shows that the electric energy produced is enough to the swimming pool except in the months where the swimming pool is closed. The consumption is higher than 50% of the produced energy, which is in agreement with the Portuguese policy.

Figure 7 shows that the backup boiler will work only during six months per year with a small contribution for the overall thermal energy consumption.

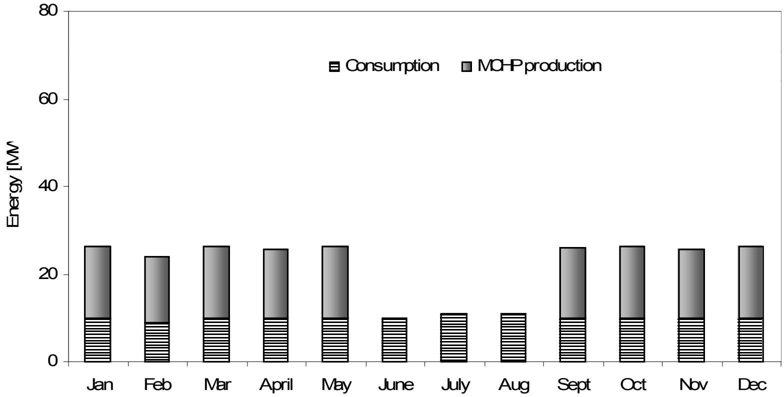

Figure 6. New profile of the electric energy.

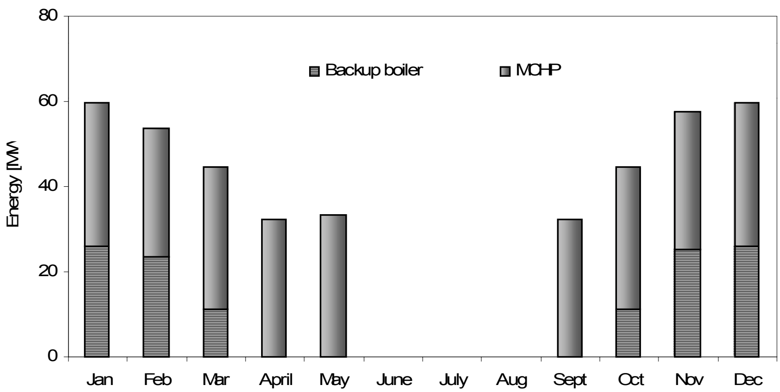

Figure 7. New profile of the thermal energy.

Table 3 shows the annual operational simulation where the maintenance costs were considered to be 0.012 €/kWh$_e$.

Table 3. Annual economic evaluation

Billing element	**Producer charge (€)**	**Consumer charge (€)**	**Network charge (€)**
Propane	27.043	-	-
Active energy	1.200	9.140	6.683
Fixed charge	223	1.099	-
Power	62	-	-
Power peak hours	-	-	1.334
Ct × EECm × IPCdez ÷ IPCref	-	-	721
Thermal energy	-	15.313	-
Maintenance costs	1.827	-	-
Total	**30.354**	**25.552**	**8.739**

This new condition of energy sources allows an annual operational result of 3.937 €. The overall cost of the MCHP system was about 27.000 €, which allows a payback of about 7 years.

7 Conclusion

A MCHP system supplied by propane was studied and successful implemented in a swimming pool. The selected MCHP system does not have a higher power due to Portuguese energy policy limitations. In the summer when the swimming pool is closed no thermal energy is consumed, therefore the MCHP system should run only in the peak hours. This situation eliminates the high cost of the active energy and mainly the value of the power in peak hours. The economic simulation of the system functioning during one year has shown the profit of about 4.000 €. The return of the investment is completed in about seven years. We must be aware that this result would be more interesting if we use natural gas, which will be possible in a near future.

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INCORPORATING ENVIRONMENTAL AND ECONOMIC OBJECTIVES IN THE DESIGN OF DISTRIBUTED GENERATION AND DISTRICT HEATING PLANTS THROUGH EXTERNALITIES: DEALING WITH UNCERTAINTY.

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Distributed generation (DG) appears to be the state of the art solution to meet growing energy demand efficiently, especially if combined with heat recovery (cogeneration) and in urban areas, where cogeneration systems can be optimized by the combination with district heating. Reduction in overall fossil fuel consumption and associated global emissions – especially in terms of greenhouse gases (GHG) – are most important benefits associated with district heating. However, in public decision making concerns often arise as regards local air emissions, which are frequently neglected in preliminary feasibility studies. Models adopted in early design stages, in fact, mainly aim at cost optimisation and emissions are usually calculated afterwards, often focusing on GHG only. More articulated approaches, typical of regional and national energy planning, are seldom used for local small scale projects. In the present study, an extended model pursuing both economic and environmental objectives by means of external costs is developed to support the synthesis of optimal cogeneration and district heating systems in terms of economic, local and global environmental performances. The approach is applied to a project of natural gas engine based cogeneration and district heating in North-Eastern Italy. Optimal sizing and foreseen operation of the system, including several cogeneration units and serving, among others, a large hospital, will be presented and compared with the results of economic optimisation models, thus assessing the effect of pursuing compromise solutions aiming at more satisfactory environmental performances. The issue of uncertainty in externalities modeling is discussed, and a sensitivity analysis of optimization results to ranges of external cost values is presented.

1 Introduction

International agreements and national commitments to abate greenhouse gases, rooted in growing concerns about climate change and associated with various economical energy policy measures (e.g. carbon taxes), made the reduction of CO_2 and of its equivalents a major motive, along with the reduction of primary energy use, for enhancing the use of distributed cogeneration systems as an alternative to traditional, separate (remote) production of power and (local) production of heat. Due to its recognised global effects, CO_2 is also considered a more credible index for environmental assessments than other emissions [1]. For these reasons, assessing environmental impacts only in terms of carbon dioxide equivalent emission reduction has become a common practice in designing municipal cogeneration and district heating systems [2], especially when economical objectives are pursued by decision support models based on optimization procedures [3]. However, since small cogeneration and district heating systems are conceived and authorized locally, and as local administrators have to cope with local pollution and air quality issues, it is rather opportune to support the design of such energy systems with decision aid instruments taking also other causes of pollution into account. This is – among others – the case of the pre-feasibility study on a distributed cogeneration system which was performed by the authors on behalf of the Municipality of Udine in year 2004. For that purpose, an economical optimization model was developed, which is described in detail elsewhere [4] and summarized in following paragraphs as far as necessary to understand the context of changes and of calculations. CO_2 equivalent emissions and primary energy savings were the only sustainability indicators considered in that study; they were calculated after performing the optimization procedure, while attention was centred on economical performance, expressed as equivalent annual costs to form the single objective function. This choice was justified by the necessity of attracting all potential stakeholders to support a project which would, in any case, improve local energy efficiency, and of involving them in the decision making process. Once the project encountered the approval of most involved parties, as general economic and energy saving benefits were commonly recognized, the discussion was gradually focused to technical solutions. Concerns from some stakeholders on implications of the project and on environmental impacts beyond CO_2 emissions still arouse in a unspecific manner. Additional work is then required to support the development of a discourse, so that decision makers who will be further involved in executive stages may act at a higher level of awareness: the study, which is presented in this paper, has been developed for that purpose.

Hence, the aim of the present work is to include a wider range of pollution indicators in the evaluation and in the very design of the system. We want to select and apply a methodology that suits with a early development stage of the project and yet allows to incorporate economical and environmental indicators within one evaluation framework, as more desirable energy planning models do [5], [6], rather than regarding environmental impacts as a secondary objective, to be described and quantified *after* economical optimality is achieved. The remainder of this paper is thus organised as follows: in the section 2, most relevant aspects of the case study are described and results obtained by the authors using the economic optimisation models are summarized. In section 3, the selected methodology, i.e. incorporation of external costs bound to air emissions, is presented, while estimates obtained for emissions and associated externalities are reported in section 4. Finally, section 5 compares new and former optimal designs and operation strategies, trying to draw general indications.

2 The case study and the economic model

The system of concern embraces several public buildings located in the North-western part of Udine, a town of about 90000 inhabitants situated in North-Eastern Italy. Among the considered buildings, the Civic Hospital is the major one, both in terms of size and of energy requirements: not only, in fact, it is the largest building of the group, but also, in order to guarantee comfort conditions to in-patients, higher temperatures than in other civil buildings should be maintained and hospital heating systems should operate 24 hours a day, unlike typical community buildings, such as schools or offices, having a limited number of daily opening hours. Power demand is also large, due to medical equipment and, in summer, to air conditioning. Since the hospital is now undergoing major renovations, whereas oldest pavilions are being abated and substituted by new, larger ones, also existing energy facilities are being refurbished and additional capacity will be required: peak loads summarized in Table 1 are estimates of future requirements as of year 2007. Currently, the hospital is served by natural gas boilers and steam generators meeting the heat demand of existing buildings. As for power demand, the hospital is, at present, totally depending on the national grid, apart from small oil based power generators operating in case of blackouts only. The scientific pole of the University, formed by three buildings, also belongs to the group of facilities of concern, all located within an area of some 7 km^2 centred around the headquarters of a local multi-utility, currently engaged in natural gas and water distribution, which could be the prospective leader of energy saving initiatives to be developed in the area. Especially energy intensive are two swimming pools, placed in the area, respectively comprised within a leisure and culture centre, and within a boarding-school complex.

Table 1. Technical features of the system of buildings of concern.

Centre	**Heated volumes [m^3]**	**Thermal peak load [kW]**	**Power peak load [kW]**	**Thermal energy consumption [kWh/year]**	**Electrical energy consumption [kWh/year]**
Hospital (H)	520000	10212	3263	41898303	18183222
University building block 1 (UB1)	150000	3461	944	3155747	3792845
University building block 2 (UB2)	30000	939	153	746122	719065
University building block 3 (UB3)	22600	818	130	782183	844000
Boarding school with swimming pool (BS)	70700	1042	132	2958264	556118
Utility – natural gas distributor (UT)	45000	1307	180	973770	790724
Culture center with swimming pool (CC)	20700	1067	80	6404179	570024

Several technical solutions have been proposed for a novel configuration of the system. In particular, three configurations attracted the attention of most investors, and have been therefore further investigated in this study. The first represents a minimal configuration, corresponding to the installation of opportune cogeneration engines meeting the hospital power demand all over the year; recent blackouts pressure the hospital to be independent from an energy viewpoint. For convenience and reliability reasons, a boiler should be foreseen and dimensioned to meet heat demand by the hospital not covered by heat recovery from the engines. Actually, hospital heating requirements are so large, that larger cogenerators could be installed, selling surplus produced power on the liberalized energy market. This activity should be clearly undertaken by an external energy saving company, which would manage the hospital thermal station, using it to collocate reciprocating engines having a higher capacity than the power load of the hospital: this situation is studied as a second scenario. The third scenario sees the hospital thermal station as a starting point for a district heating system serving all the previously identified buildings in the area of concern; successive expansion could lead to connect private homes to the network too. To size the systems optimally in the three cases, a mixed integer programming time dependent model aiming to systems cost minimization was conceived [4], which allows to consider energy demand variations along the day and the year and hourly energy sale price differentiation as currently proposed by Italian Energy Bureau. The model has been described in detail elsewhere [4]; in the following, we just present most relevant variables and parameters and the objective function in a simplified form.

The main variables of the model are:

- Thermal capacities *CapTh* [kWt] for each heat technology *techTh* and production unit uTh_z selected in each center *z*.
- Electrical capacities *CapEl* [kWe] for each production unit uEl_z selected in each center with electrical energy technology *techEl* (e.g. low or high rev. engines).
- Thermal power *PowTh_prod* [kWt] and electrical power *PowEl_prod* [kWe] produced by each unit uTh_z and uEl_z in period *t*.
- Electrical power *PowEl_sale* [kWe] produced for sales by each unit uEl_z in period t.
- Thermal power *PowTh_diss* [kWt] which is dissipated in those periods where electrical energy is conveniently cogenerated in absence of a related thermal demand.
- Natural gas amounts *GasQty(us)* needed to produce energy flows for different uses *us.* Different energy destinations (internal consumption, sales, etc.) imply different gas prices due to current tax system, which encourages virtuous form of energy production, such as cogeneration and district heating.
- Electrical energy *ElQty* purchased by hospital or AMGA center when cogenerators don't cover internal requirements because it results more convenient to sell electrical energy rather than self consume it. Binary variables (*bin*) are introduced as needed to model scale economies and Italian tax system.

Main parameters taken into account are:

- Investment costs, characterised by a variable component *CostVarInv* proportional to facility sizes and a fixed component *CostFixInv*, which is instead size independent.
- Costs related to district heating: pipeline installation *CostDHpipe* and operation costs *CostDHop* (pumping, personnel, maintenance) of the network.

- Fuel costs *CostGas(us)* dependent on final use *us* and purchased electrical energy costs *CostEl.*
- Operation costs of energy electrical (*El*) and thermal (*Th*) facilities *CostOp*, including personnel, administration and maintenance.
- Dissipation cost *CostDiss*, related to costs of electrical energy consumed by dissipators.
- Electrical energy sale price *PriceEl*, function of each time periods *t.*
- Thermal and electrical energy demand of each center in every time period *t*, calculated as the product of average required power *PowTh_dem* and *PowEl_dem* by each center *z* in that period and its time length *h(t)* [h].
- Technical performance measures related to each technology such as efficiency, power to heat ratio (α), dissipation coefficient and so on.

The objective function (equation 1) minimizes the total cost per year of the energy system in each previously identified configuration; investment costs are expressed on a yearly basis by introducing the annuity factor *ann* depending on expected life of each facility:

$$\min\left\{\begin{array}{l}
\sum_{uTh_z,techTh} ann(uTh_z,techTh)\cdot\begin{pmatrix} CostVarInv(uTh_z,techTh)\cdot Cap(uTh_z,techTh)+\\ binTh\cdot CostFixInv(uTh_z,techTh)\end{pmatrix}+\\
\sum_{uEl_z,techEl} ann(uEl_z,techEl)\cdot\begin{pmatrix} CostVarInv(uEl_z,techEl)\cdot Cap(uEl_z,techEl)+\\ binEl\cdot CostFixInv(uEl_z,techEl)\end{pmatrix}+\\
\sum_{us,uTh_z,techTh,t} CostGas(us,uTh_z)\cdot GasQty(us,uTh_z,techTh,t)+\\
\sum_{us,uEl_z,techEl,t} CostGas(us,uEl_z)\cdot GasQty(us,uEl_z,techEl,t)+\\
\sum_{uEl_z,techEl,t} CostDiss(t)\cdot PowTh_diss(uEl_z,techEl,t)+\\
\sum_{uTh_z,techTh,t} CostOp(uTh_z,techTh,t)+\sum_{uEl_z,techE,tl} CostOp(uEl_z,techEl,t)+\\
\sum_t CostEl(t)\cdot ElQty(t)+annDHpipe\cdot CostDHpipe+\sum_t CostDHop(t)-\\
\sum_{uEl_z,techEl,t} PriceEl(t)\cdot PowEl(uEl_z,techEl,t)\cdot h(t)
\end{array}\right\} \tag{1}$$

To allow homogenous evaluation and for the sake of simplicity, the system is thus seen as a new designed one, rather as an expansion or variation of an existing one. This assumption is valid in that we assume that most considered boilers are anyway approaching their expected duration: as a consequence, the design and installation of new systems would be anyway required, rather than the simple refurbishment or conservation of existing ones. Positive cash flows from electrical energy sales are then taken into account by related incomes. A number of constraints is introduced to model energy flow balances and to guarantee technical compatibility of selected solutions. In particular, we model partialisation capabilities of the engines by introducing an additional binary variable *idPflow,* function of site, unit, power generation technology and period, equalling 1 if at site *s* the unit *p* generates power through technology *y* in period *t*. If any power is produced, that is, if *idPflow*=1, this must be more than the product of maximum power generation capacity by the engine by the coefficient of partialisation. New features added in the last version of model allow to previously fix the number of engines to be installed in each site. Due to the fixed cost component in investments and to higher efficiencies and smaller maintenance costs of bigger engines, in fact, cost minimization would force the design to the selection of a minimum number of engines (typically one), which appears undesirable for the sake of reliability, especially for hospitals. An additional integer parameter has been introduced to set a lower bound to the number of engines, corresponding to the requirements of capacity subdivision expressed by the engineering staff of the hospital. Even though the objective function does not change, so the system is considered always as a newly designed one and not as an expansion or modification, the capacity of one of the engines and of one of the boilers at the hospital has been also fixed, at 650 kW_{el} and 6000 kW_{th} respectively, since they have been newly purchased as a temporary compensation in the transition between current and future pavilion configuration and should be utilized in the following; the optimization system was required to define the size of at least other two engines and – if opportune – of further boilers. Results obtained with this economic optimization model for various scenarios are outlined in Table 2.

Table 2. Optimal solutions and performances of various configurations under economic design criteria.

Scenario	**CHP engines installed at the Hospital (power capacity, kW_{el})**	**Peak load boiler capacity (kW_{th})**	**Net present value of the investment (€)**	**Pay back period (years)**	**Primary energy savings (TOE/ year)**	**Globally avoided emissions of CO_2 (tons/year)**
Scenario 1	650 kW 1600 kW 1050 kW	6100 kW 2000 kW	7610652 €	2.87 years	3113 t/year	6671 t/year
Scenario 2	650 kW 650 kW 5700 kW	6100 kW	13563481 €	3.15 years	5833 t/year	12474 t/year
Scenario 3	650 kW 650 kW 8400 kW	6100 kW 800 kW	17998702 €	3.52 years	7109 t/year	14934 t/year

If the environmental assessment of the project were based on primary energy savings and avoided emissions only, the third scenario would result as the most beneficial one. Also from an economic viewpoint, the light increase in the simple payback period is abundantly compensated by the higher net present value. Thus, using these criteria the best solution appears the installation of a very large (8400 kW_{el}) gas engine, supported by two small ones acting as a minimum safety equipment and integrated by the newly acquired boiler and by an additional, smaller one.

3 Selected methodology

To incorporate environmental effects in the optimization procedure, two complementary methodological streams are followed in literature, namely multicriteria analysis and monetization [5,7]. For multi-criteria analysis and for the whole body of multi-criteria decision making, hundreds of methods [6] have been proposed and applied to energy planning. In particular, according to Hobbs [1], multi-criteria approaches can be grouped into two classes, that is prior articulation methods and interactive methods. While prior articulation methods the preferences of decision makers or of groups of individuals are previously quantified within utility functions and then incorporated as objectives in optimization models, or used to rank a discrete set of alternatives, interactive methods offer to the user several trial alternatives, whose evaluation by decision makers then gives information to iteratively develop additional alternatives. Due to time consumption and group management implications of the latter class of methods, planning is dominated by prior articulation methods, which, relying on utility functions, share many features with the second methodological strand, that is monetization. Monetization is usually carried out by incorporating in energy prices so called external costs, i.e. those costs imposed on society by the impacts of energy production on human health and on the environment.

Monetization has inherent limitations, depending not only on lacking or evolving scientific knowledge (e.g. in terms of epidemiological results), but mainly on the ethical aspects of unavoidable value judgements (see the issue of using and determining the value of statistical life in [8] and in [9]) and of the problem of boundary setting (see [10]), in terms of considered impacts on creatures and human beings in space and time (see the problem of discount rate in [9]). These problems limit the applicability of externalities for the purposes they were originally meant to, such as supporting policy makers in determining energy and pollution taxes or subsidies, and lead some authors to argue that multi-criteria approaches still constitute the more rigorous means to incorporate environmental concerns in energy decisions [10]. Nevertheless, it is recognised also by authors inclined to multi-criteria decision making that monetization has the advantage of “measuring values for the entire public, rather than for a subset of perhaps unrepresentative stakeholders”[5]. In our view, notwithstanding the large variability in the values of energy externalities, the fact that monetary values associated with environmental damages from energy conversion derive from standardized methodologies [7] and that some values are available beforehand certainly help in early development stages of small projects, when concerns of stakeholders are not utterly formulated and a base of discussion for the comparison of costs and benefits is necessary. In fact, Krewitt [8] identifies in cost-benefit analysis an emerging and successful field of application for externalities; yet, reviewing literature it can be observed that these analyses are mostly performed for general assessments to support policy making [see 11]. The applications of these values to the engineering of municipal energy systems is, on the contrary, quite rare[12]. In this case, applying monetization appears, thus, both adapt under a practical perspective and interesting for its scientific and engineering implications.

4 Emission and externalities assessment

Monetization lends itself to cost-benefit and engineering evaluations in that they do not need to quantify *all* external costs, but only those of interest for the system of concern. For specific case studies, a limitation of the system, including only few impacts within the system boundaries, can give sufficient indications to the engineer on how to proceed and on which design options are most critical. As for cogeneration and district heating studies, in particular, as all energy conversion technologies are based on fossil fuels, focusing on the effects of airborne emissions is regarded as a meaningful choice, as testified by existing specific studies[12], and by more general assessments of energy externalities [13]. Coherently, also the ExternE methodology [8], produced by most authoritative studies within the European Community for assessing externalities of energy generation, changed its initial aims from the calculation of external costs per kWh to the calculation of specific damage costs per unit of pollutant emitted, which can be transferred more easily to a broader context. The methodological core of ExternE is represented by the Damage Function approach, a "step by step analytical procedure examining the sequence of processes through which burdens associated with a particular polluting source result into environmental damage. This methodology has been implemented within the EcoSense software, whose on-line version [14] has been used for this study. Focusing on airborne emissions, the starting point to calculate the total atmospheric burden are the characteristics of fuels and conversion technologies/activities, allowing the determination of emission factors. According to the emission factors method, total emission referred to a given area can be calculated by multiplying the activity indicator (for instance fuel consumption) by the corresponding emission factor FE, representing the emission per unit by the source. The choice of emission factors represents a critical aspect: the effort to compile inventories of such factors dates back to the late Seventies, as for the Usa and the EPA, and to the mid Eighties, as for Europe and the CORINAIR project. Specifically, in the bounds of the CORINAIR project the SNAP nomenclature was developed, which classifies human and natural emission generating activities in macro-sectors, sectors and activities, embracing – in the latest versions [15] – eleven macro-sectors, 260 activities and an extended group of pollutants. A more detailed methodology was then developed within the European Environment Agency [15], taking into account besides sector (fuel combustion for energy conversion pertains to the first macrosector) and activity (domestic heating, district heating etc.) also the adopted technology. In recent years, inventories and software packages for process or product life cycle assessment have been developed, which adhere to EEA standards. In particular, the GEMIS inventory [16] which was adopted for this study considers technologies in more detail, taking into account plant size with a finest resolution than EPA [17] inventories. Comparing mentioned inventories with the GEMIS database, a good level of consistence can be observed as order of magnitude, whereas the capacities considered by the GEMIS model better correspond to the small engine size in distributed generation than the wide ranges (e.g. "up to 50 MW") from general inventories. Thus, values derived from the GEMIS inventory and displayed in Table 3 were finally assumed as emission factors.

Table 3. Emission factors and external costs for single pollutants.

	Emission factors for engines [kg/kWh]		**Emission factors for boilers [kg/kWh]**	**External costs per emission unit [€/kg]**
Polluting Agents or GHG	***Engine Capacity up to 750 kW$_{el}$***	***≥1000 kW***		
SO_2	$1{,}540 \cdot 10^{-6}$	$1{,}540 \cdot 10^{-6}$	1,540 · 10-6	4.10
NO_x	$362{,}75 \cdot 10^{-6}$	$453{,}43 \cdot 10^{-6}$	362,750 · 10-6	3.76
PM_{10}	$9{,}0687 \cdot 10^{-6}$	$9{,}0687 \cdot 10^{-6}$	0,907 · 10-6	19
NMVOC	$27{,}206 \cdot 10^{-6}$	$27{,}206 \cdot 10^{-6}$	32,647 · 10-6	0.238
CO_2	$199000 \cdot 10^{-6}$	$199000 \cdot 10^{-6}$	199000 · 10-6	0.019
CH_4	$21{,}765 \cdot 10^{-6}$	$27{,}206 \cdot 10^{-6}$	32,647 · 10-6	0.437
N_2O	$9{,}0687 \cdot 10^{-6}$	$18{,}137 \cdot 10^{-6}$	6,529 · 10-6	5.62

The on-line version of the EcoSense software [14] allows the calculation of specific external costs associated to SO_2, NO_x, fine particulate (PM_{10}) and non metallic volatile organic compounds (NMVOC). These pollutants mainly impact on local air quality, as NOx, along with NMVOC, react in the atmosphere to form ozone, whose strong concentrations in urban areas may result in short term respiratory problems and irritation of mucous membranes; similar impacts derive from SO_2 emissions [13]. Fine particulate, on the other hand, also operates as a vector of toxic substances on its surface: along with NMVOC, PM_{10} may be bound to pathogenicity at respiratory level and cancerogenicity in the long term. Beside such local impacts, SO_2 and NO_x also have geographically wider impacts as they contribute to the formation of acid rain, which threatens ecosystems and vegetation in particular. However, acid rain effects are not considered within the EcoSense framework [8]: this fits well to the objectives of the study, as local effects on human health represent the primary concern of local decision makers. The externalities of greenhouse gases, on the other hand, can be also separately calculated with the EcoSense model, obtaining the values also summarized in Table 3, where external costs associated with damages to human health were considered. The EcoSense models distinguishes between higher and lower stacks, which lead to wider or more local impacts. We considered emissions from low stacks, as those of such relatively small municipal plants are meant to be, thus the effects of concern will be mainly local. The focus of the decision making being local, we neglected avoided externalities from CO_2 equivalent emission reduction. Thus, external costs of cogeneration and district heating systems are calculated by adding externalities from various emissions (including CO_2 equivalents) to fuel costs. Basically, the cogeneration and district heating system is regarded, in the optimization perspective, as a new built one satisfying a new energy demand rather than as an expansion or modification of existing subsystems, which is coherent with the modelling approach previously used for economic optimization only.

As for power generation, distributed generation is not substitutive, that is to say, we consider it an additional generation, which does not cause the outage of a corresponding average remote capacity. For the analyzed system, the substitutive option has been partially analysed for the present case study in [18]: it has been shown that optimized system configuration are only marginally affected by incorporating externalities reduction from remote power generation. For this reason and due to focus by decision makers, we concentrate on the additional view in this investigation. Thus, externalities are not incorporated in power purchase or wholesale prices, but only internalised among fuel costs. The idea is, designers should select a system having minimum impact, both in local and global terms. Hence, both externalities from CO_2eq and from local pollutants are added up to fuel costs.

4.1. *Uncertainty in externalities estimation*

A major criticism to the externalities approach lies in uncertainty of damage cost. Rather than model and data uncertainty, the major cause of uncertainty is of an ethical and human nature [19], in that damage cost estimation relies in turn on attributing a monetary value to losing one year of human life. This applies especially to our study, since for pollutants we only consider impacts on human health. External costs presented in Table 3, which are deemed as the most reliable estimates, presume a value of 75,000 € per year of life lost. Methodological developments [19] indicate a minimum of 27,240 €/y and a maximum of 225,000 €/y as boundaries for sensitivity analysis. External costs ranges for various pollutants are have been calculated accordingly and are presented in Table 4. As for GHG emissions, which were the second considered cause of damage, the value of the external costs for CO_2 equivalents depends on which possible damages connected to climate change are taken into account, such as for instance extended floods or more frequent hurricanes. In accordance with [19], we assume 9 €/kgCO_{2eq} as a minimum value and 50 €/kgCO_{2eq} as a maximum for sensitivity analysis, while values displayed in Table 3, associated with a cost of 19 €/kgCO_{2eq}, are the most reliable estimates, which leads to the values reported in Table 4 for single greenhouse gases.

Table 4. Ranges of external costs for sensitivity analysis.

Pollutant	Minimum external cost [€/kg]	Maximum external cost [€/kg]
SO_2	2.38	9.53
NO_x	2.16	8.78
PM_{10}	9.67	48.2
NMVOC	0.201	0.353
CO_2	0.009	0.05
N_2O	2.66	14.8
CH_4	0.207	1.15

5 Results and discussions

The model was implemented in AMPL® and solved with the commercial solver CPLEX ®. The yearly equivalent time horizon was subdivided in 41 sub-periods. This allows not only to account for seasonality of heating requirements, but, above all, to model the variation of power wholesale prices, which are higher in peak demand periods (morning and early afternoon hours in summer and late afternoon hours in December), lower in weekends and during the night. The system is assumed to have a lifetime of 15 years and an interest rate of 7% is fixed in order to meet investors profitability expectations. Actualisation factors are calculated accordingly.

In the following, result obtained for these two cases will firstly be compared with the previously discusses base case of economic optimization only. Secondarily, we account for ranges of external costs comparing design alternatives under various assumptions for value of life and for climate change damages.

5.1. *Results for most reliable estimates of external costs*

Table 5 summarizes technical features of the energy systems obtained under various assumptions. In particular, the original economic evaluation, non including externalities, is presented as base case. The "standard externalities" case assumes the most reliable estimates for year of life lost (75.000 €) and for climate change damage (19 €/t CO_2eq) and consequent values for external costs. It can be observed that including external costs within the objective function substantially changes the optimal configuration of the system only in the second and third scenario. As for the first, we concluded that the constraint of constantly meeting hospital power demand is so narrow that it makes optimal sizing practically insensitive to specific costs variations such as internalisation of externalities. As for the second and third scenario, it can be observed that integrating monetized environmental impacts into the objective function leads to a substantial reduction in global engine size: in the third and most significant scenario, for instance, the largest and slowest engine (750 rpm) has an optimal size of 8400 kW, if we strive for economic optimisation, of 5900 kW if we take into account remote power generation externalities too (substitutive distributed generation). This goes along with a significant decrease in dissipated heat: dissipated heat amounts yearly to more than four thousand MWh in the base case, to a little bit less than 2000 MWh considering externalities. Correspondingly, power sales reduce almost by the half. In other words, if we would just pursue profit maximisation we would operate the plant whenever sale prices are high, aside from thermal energy demand; as marginal costs of larger gas engines are smaller, it is also opportune to maximise the size in order to produce and sell as much power as possible in peak demand periods. If we consider externalities, power generation is only performed when an existing thermal energy demand justifies the generation of pollutant emissions. In this context, it is interesting to observe that in the third scenario, under externalities consideration, heat dissipation is lower than in the first, thanks to load harmonization derived from district heating development. Paradoxically, theoretically avoided emissions and primary energy savings are lower when we take externalities into account and avoid dissipating heat from CHP systems; it should be observed, however, that this would be valid only under a substitution assumption. As for other emissions, presented in Table 6, highest values are obviously achieved in the third scenario, which – however - cannot be compared with the other two in absolute terms as the systems scope – embracing district heating – is quite different.

A comparison can be nevertheless attempted by considering annual equivalent costs, to which internal and external costs of fuel used in small scale boilers substituted by the DH network in Scenario 3 have been added to equivalent systems cost in Scenario 1 and 2. In this way, we have an estimate of how much do various system cost to the local community.

Local external costs have been isolated in the second column of Table 6: notably, a small cogeneration system and a definitely larger one, which is however coupled with a district heating system, create more or less the same damage to the local community, whereas a larger benefit, both in terms of creating worth and services for the local community and in saving primary energy and avoiding global emissions, can be achieved in Scenario 3.

Table 5. Technical and energy results of externalities evaluations.

	External cost determinants	Total power generation capacity [kW]	Total heat generation capacity [kW]	Local boilers of potential network uses [kW]	Power sales [MWh/year]	Power purchases [MWh/year]	Primary energy savings [TOE/year]	Dissipated heat [MWh/year]
Scenario 1	All cases	3300	8100	8634	0	0	3,113	1975
Scenario 2	Base case, no external costs	7000	6100	8634	17880	0	5,833	3789
	Standard externalities	6600	6100	8634	16900	0	5,773	2890
	Low externalities	6600	6100	8634	17050	0	5,776	3083
	High externalities	6300	6100	8634	15810	0	5,701	1847
Scenario 3	Base case, no external costs	9700	6900	0	30564	7,273	7,109	4330
	Standard externalities	7200	10000	0	17580	7,273	5,817	1954
	Low externalities	8200	8800	0	26737	7,273	7,132	2660
	High externalities	6300	11200	0	9399	7,273	4,664	635

Table 6. Economic and emission indicators.

	External cost determinants	Annual equivalent cost, including local externalities [€/year]	Local external costs [€/year]	Simple payback period [years]	Globally avoided CO_2eq emission [t/year]	Pollutants			
						SO_2 [kg/year]	NOx [kg/year]	PM10 [kg/year]	NMVOC [kg/year]
Scenario 1	Base case, no external costs	3282323	0	2.87	6671	1.07E+02	2.53E+04	4.54E+02	2.02E+03
	Standard externalities	3465530	183207	2.87	6671	1.07E+02	2.53E+04	4.54E+02	2.02E+03
	Low externalities	3381351	99028	2.87	6671	1.07E+02	2.53E+04	4.54E+02	2.02E+03
	High externalities	3728468	446145	2.87	6671	1.07E+02	2.53E+04	4.54E+02	2.02E+03
Scenario 2	Base case, no external costs	2765273	0	3.15	12474	1.34E+02	3.89E+04	7.84E+02	2.36E+03
	Standard externalities	3005459	236461	3.09	12386	1.31E+02	3.79E+04	7.64E+02	2.31E+03
	Low externalities	2896787	129586	3.09	12383	1.31E+02	3.79E+04	7.67E+02	2.32E+03
	High externalities	3356628	561225	3.08	12277	1.27E+02	3.68E+04	7.40E+02	2.26E+03
Scenario 3	Base case, no external costs	3297420	0	3.52	14934	1.82E+02	5.31E+04	1.06E+03	3.23E+03
	Standard externalities	3537342	184069	3.31	12452	1.58E+02	4.46E+04	7.92E+02	2.89E+03
	Low externalities	3423838	118888	3.37	15192	1.73E+02	5.02E+04	9.78E+02	3.09E+03
	High externalities	3813668	379598	3.32	10061	1.44E+02	3.94E+04	6.25E+02	2.70E+03

5.2. *Dealing with uncertainty: the impact of external cost estimates*

The point in uncertainty assessment is to observe, to what extent does the optimal configuration and costs change when different values for externalities are assumed. As for configuration, the first scenario is practically unsensitive. The second is quite robust: cogenerator size reduction is just about 10% moving from zero to maximum externalities, while substantial changes occur in operation, with a significant decrement of power generation in dissipative mode. The district heating scenario is the most sensitive one: reduction of optimal engine size moving from low to high external cost estimates is about 24%. With respect to sole local externalities, it is interesting to observe that by low and average estimates of external costs Scenario 1 remains the one causing less additional damage to local community, while if we assume higher external unit costs Scenario 3 is the best performing. This is probably due to the weight of external costs within the objective function in scenario 3,leading the optimization procedure to force systems to operate at highest possible efficiency, reducing heat dissipation to minimum values.

6 Conclusions

The limits of externalities emerge even in small scale engineering application, in that technical and emission values appear -to some extent –to be watered down in monetization. A general issue, which deserves further attention in its specific application to energy systems design, is related, rather than to monetization, to the very problem of setting the boundaries of the systems (e.g. considering local or global perspectives, substitution or addition of new systems to the national power generation system). Nevertheless, especially for small contexts, where decision makers rather have a local scope and necessarily limited experience in dealing with complex and global issues of energy planning, including externalities in cost analysis may be an useful starting point for further discussion. Furthermore, this study demonstrated that incorporating externalities into engineering design supports leads to a more rational design of energy systems, avoiding oversizing and heat dissipation. Since sensitivity to external cost values appears however quite important, further research is required to limitate the variation of external costs values to be used for a project or to reduce its impact. Direction for further research would then be towards participative approaches, creating consensus on definite values for specific projects and towards more robust optimization.

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ANALYTICAL PREDICTION OF SPREAD SCENARIOS FOR SMALL-SCALE CHP SYSTEMS

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In this paper the potential for penetration of small scale cogeneration is assessed at EU level, starting from an overview of the present CHP market. The new EU Directive, representing a milestone in the EU policy for the growth of cogeneration, requires further provisions and large financial efforts to favour increases in the CHP installed capacity and to contribute in overcoming the main obstacles to the spread of polygeneration. Targeting the incentives to all size plants is verified not to be an effective approach, because of the different obstacles to the spread of CHP systems existing in small and large applications. After identifying the main factors influencing the CHP potential in a liberalized energy market, an original index expressing the opportunity for new profitable CHP installations is introduced. Future scenarios for CHP penetration at EU and national level are presented and the expected effects of different policy actions.

1 Introduction

The promotion of polygeneration has been representing for many years a pillar among the EU policies for the rational use of energy (RUE), due to the benefits that these systems produce in terms of primary energy saving and reduction in pollutants' emissions.

Cogeneration is expected to play a primary role for the reduction in energy intensity and the achievement of emission reduction targets, as evident when examining the two main policy acts published in the last two decades:

- The communication from the Commission on "A community strategy to promote combined heat and power (CHP) and to dismantle barriers to its development", where the objective is fixed for a doubling of the share of CHP from 9% (at 1994) to 18% of the total gross electricity generation of the Community produced by CHP by the year 2010.

- The Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market, which fixes the criteria to assess a system for the combined production of heat and power as high efficiency cogeneration.

Furthermore, many other EU acts introduce provisions in order to promote the spread of combined production; among these, the Directive 2003/54/EC, allowing Member States to give dispatching priority to CHP installations, and the Directive 2002/91/EC requiring a technical, environmental and economic feasibility analysis for all new buildings with a total useful floor area of over 1,000 m^2 could be mentioned. The new legislative framework at EU level empowered and harmonized different regulative approaches which had been working for many years in most member states (in Italy, for instance, the CHP legislation originated since eighties).

A large number of measures has been adopted, primarily at national level, in order to drive the spontaneous equilibrium of energy markets toward a large spread of cogeneration; from this perspective, the EU action has been weakened by the risk to produce distorting effect in the free market. The above mentioned efforts at institutional level have not produced the expected results yet; in the last two years a market stagnation has been observed and, in some countries, CHP systems are even being shut down.

A main concern regards the need to make polygeneration a viable solution for energy supply, from an economic viewpoint; in fact, the strategy of private operators is oriented to the direct economic return, being the social effects of CHP (i.e. energy saving or CO_2 reduction) an interest of the community and of institutional bodies. Further, polygeneration is living distinct phases in different member states, as a consequence of the local external factors; if the common energy market was actually operating since now, unhomogeneity would be its main characteristic.

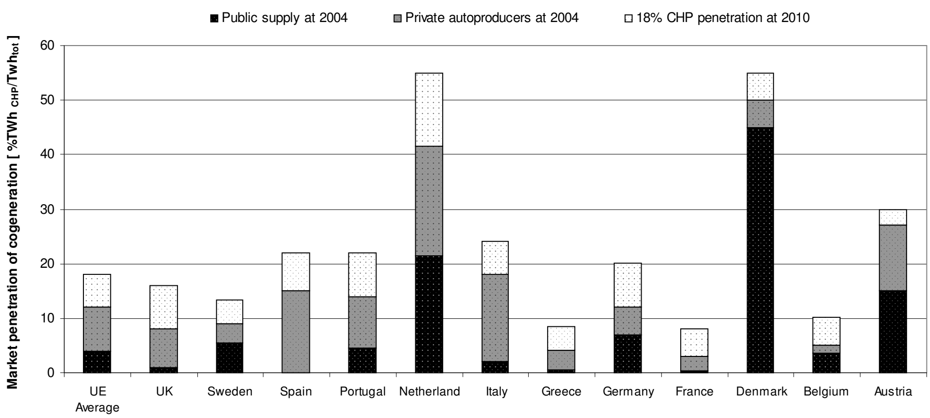

Figure 1. CHP penetration in different EU member states and expected growth in the 18% CHP penetration scenario outlined by the EU Commission.

After a brief analysis of legislative and market conditions influencing the attractiveness of polygeneration and of the current legislative and market provisions in different countries, an original indicator is defined in order to assess whether the external conditions favour a complete exploitation of the local potential for small-scale CHP.

In order to simplify the analysis, only CHP system operating with fossil fuels will be considered (where a large prevalence exists for natural gas systems).

2 An overview on cogeneration markets in Europe

According to the available informations, the total installed CHP capacity in Europe at 2004 slightly exceeded 80 GW_e, with a total production in the order of 270–280 GWh [1].

In order to reach the above mentioned 18% of total electricity production by CHP systems, the capacity at 2010 should be at least 125–130 GW_e; however, this target does not represent a commitment.

In [1] the current CHP penetration in different national markets is presented, with the expected contribute to the achievement of the EU Commission's target at 2010 [2], according to the current trends.

In terms of total CHP production, the largest contributes come from Germany (more than 60 TWh), Netherlands (almost 45 TWh), Finland (27 TWh), Italy and UK (23 TWh each). Splitting the overall installed capacity between public and private owned CHP systems enables us to recognize the large differences existing in the CHP market among the European countries; in most of cases the CHP capacity of private auto-producers is much larger than the public owned CHP, but in Denmark and Netherlands where the highest penetration of polygeneration is observed due to the significant contribute of public energy utilities.

The above data include any kind of CHP production; however, a main distinction must be introduced between large cogeneration plants and small-scale/micro CHP units. In fact, two distinct markets for cogeneration exist, which are driven by different legislative provisions, fare systems and scale factors in the cost of components; thus, in many countries where a good integration of CHP production with industrial processes may be observed, a large unexplored potential exists for small scale CHP or CHCP applications for district heating/cooling or for single buildings (both in the tertiary and the domestic sector).

In this paper the attention is focused on the potential for small-scale CHP or CHCP systems, with a capacity below 2 MW_e. The main applications are in the civil sector, and in particular in the tertiary sector for customers like hotels, hospitals, offices or commercial centres, where high energy consumption for electricity, heat and, eventually, cooling make CHP auto-production an attractive option for energy supply.

The potential of small CHP/CHCP systems for buildings applications is a very controversial issue, because of the high capital investment and the irregular demand profiles, which allow the CHP group to operate for a part of the year only (usually, not more than 4,000–5,000 hours/year) thus being harder to achieve an economic feasibility.

Further, these systems have harder access to favorable financing and fuel price; as a result of the above factors, in most of European countries small-scale cogeneration only accounts for a small percentage of the total installed CHP capacity.

Specific data on the incidence of small-scale CHP on the overall installed CHP capacity can be hardly derived; however, the share of small-scale CHP capacity varies between 2 and 18% [3,4]. The analysis presented in the following of this paper aims to assess whether or not the external conditions in different countries could favour a rapid growth of the small-scale CHP market, by the light of two main factors:

- After the new EU Directive on cogeneration, it is expected that new provisions and support mechanisms will be introduced. The common rules for the assessment of high efficiency CHP only represented a preliminary condition for the implementation of new and more market-sensitive actions;
- The liberalization of energy market has developed in a very inhomogeneous manner all over the Europe; further, it was expected to favour the growth of CHP market, but it has not due to the effects produced on energy prices and which will be examined in the next section.

3 Structural and artificial factors influencing the CHP market: toward the definition of an indicator

The penetration of polygeneration in European energy market has been continuously growing, in particular in the last decade.

However it is common interest to accelerate this rate of growth and to promote the combined production in some sectors where its economic feasibility is not easy.

Further, the liberalization of energy market has quickly changed the traditional equilibrium between energy utilities and final costumers; from this perspective, CHP represents one of the most competitive Distributed Generation Technologies (DGT) and its growth is strictly related to the growing interest for decentralized power generation.

In this section the most relevant and controversial aspects related to the spread of cogeneration are presented, which are deeply discussed ahead when analyzing the singular member states and which may be classified in two main categories:

1. The opportunities for an integration of a large number of auto-production CHP units in the liberalized energy market and all the provisions regulating the connection, the energy exchange with the grid and its price.
2. The support mechanisms for the internalization of benefits produced by polygeneration systems in terms of primary energy saving and reduction in pollutants' emissions.

However, a different classification is here proposed distinguishing among quantifiable and non-quantifiable factors and oriented to the analytic definition of a synthetic gauge expressing to which extent the national regulatory and market conditions favour a spread of cogeneration.

From a theoretical point of view, most of factors could be in some way quantified; hence, in this paper the term “quantifiable” is used to indicate those parameters with a quantitative nature which can be calculated unambiguously on the base of easy market investigations.

3.1. *Quantifiable factors*

Four main factors influencing the potential market for small-scale CHP were recognized, which are listed and analyzed below in logical order:

1. *Energy price*: the cost for purchasing electricity and natural gas and the selling price for surplus electricity significantly influence the profitability of small-scale CHP applications. In the definition of the indicator for CHP potential, this factor will be intended as “average market-price of energy”; in fact, even if the energy price for CHP system heavily differs from the average market-price, the difference is expressed in terms of premiums for CHP electricity or de-taxation of CHP fuel and will be kept into account by introducing another factor, which is examined below. This approach allows not to make any distinction between purchasing and selling price of electricity, because the aforementioned monetary support mechanisms only influence the selling price. A non-dimensional parameter is used to express the energy price, namely Spark-Spread (S_{spread}), defined as ratio between the local unit price of electricity and the cost of the amount of natural gas to be consumed for the production of a unit of electricity by CHP systems:

$$S_{spread} = \frac{MP_e}{\frac{1}{\eta_{e,CHP}} \cdot \frac{3{,}600}{HLV_F} \cdot MP_F} . \tag{1}$$

   The reference efficiency of CHP systems is assumed equal to 0.33, which is a reasonable value due to the prevalence of reciprocate engines in the examined power range (size up to 1 MW_e). The spark-spread is a dimensionless parameter, usually ranging from 0.5 to 2.0 (the CHP potential grows with the spark-spread);
2. *Climate factor*: the duration of the heating season is determinant for CHP applications in buildings. In northern countries the feasibility of cogeneration system is favoured by the high demand for space-heating, which lasts for a long period (up to 6 months per year) ensuring a sufficient annual operation time of the system. In southern countries, however, CHCP systems can achieve a similar or even higher annual operation, due to the significant cooling demand during the summer period. Hence, the indicator for the assessment of the potential for small-scale CHP/CHCP must include a climate factor; it was decided to base the calculation on the number of degree days. In order to extend the validity of the analysis to small-scale CHCP applications, both the average heating and cooling degree days were considered for each country, harmonized by using the same reference temperature [5]; thus, a Total Degree Days index is introduced, sum of cooling and heating degree days where the

contribute of cooling degree days was increased by a 1.45 factor, to keep into account the COP of commercial absorption chillers. Further, where sufficient data were available, a weighted average of local degree days values was determined for each country, based on the demographic intensity of each zone. Finally, in order to adopt a dimensionless parameter, the average degree values for each country were normalized using as a reference value the lowest number of total degree days, as represented in Figure 2.

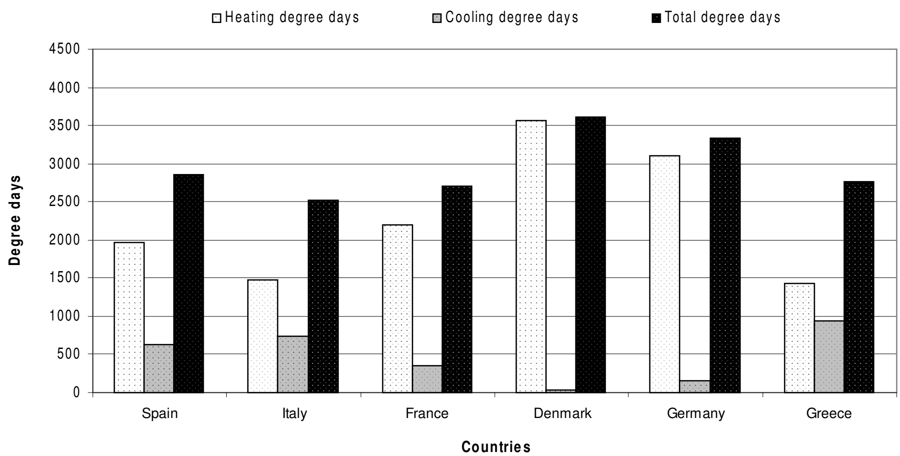

Figure 2. Average number of total degree days per country.

Thus, for each country a factor is introduced, calculated as follows:

$$TDD_{eq} = \frac{TDD}{TDD_{min}}. \tag{2}$$

3. *Monetary support mechanisms*: the spark-spread defined by Eq. 1 only gives a rough information on the market conditions exploited by small-scale CHP or CHCP systems. In fact, it is defined on the basis of average market prices and it does not take into account the large number of monetary provisions working in each country and targeted to CHP systems; among these, premiums for CHP electricity, de-taxation of CHP fuel and white certificates can be enumerated. In order to introduce properly this factor in the definition of a synthetic indicator, it was expressed in terms of multiplying factor to the market-price-based spark spread:

$$\alpha_{Sp\text{-}spread} = \frac{S_{spread,CHP}}{S_{spread}} = \frac{\dfrac{MP_e + \sum \Delta MP_e}{MP_F - \sum \Delta MP_F}}{\dfrac{MP_e}{MP_F}} = \frac{MP_F}{MP_F - \sum \Delta MP_F} \cdot \left(1 + \frac{\sum \Delta MP_e}{MP_e}\right). \tag{3}$$

Actually, two different values for this parameter must be introduced (which will be indicated as $\alpha_{Sp\text{-}spread,p}$ and $\alpha_{Sp\text{-}spread,s}$), to keep into account the differences between purchasing and selling prices of CHP electricity; both values are referred to the same MP_e and MP_F introduced in Eq. 1. The expected values for $\alpha_{spread,p}$ are in the range 1–2, while $\alpha_{spread,s}$ can assume values lower than 1, because the opportunity to sell energy out of the free market with a dispatching priority and the safer supply from large utilities frequently leads to selling price of small-scale CHP electricity lower than the average market values (even considering any support mechanism).

Both support mechanisms increasing the selling price of CHP electricity or reducing fuel cost by partial or total de-taxation, are inspired by environmental or energy saving purposes; the values of $\alpha_{Sp\text{-}spread}$ testifies the concrete efforts at institutional level for the promotion of polygeneration technologies. In this sense, the EU position is remarkable, encouraging independent support actions to be taken at national level in respect of the transparency and neutrality principles the common energy market is based upon;

4. *CHP knowledge*: one of the factors most influencing the short-medium term potential for a capillary penetration of clean technologies is the common sense about it. This is true for small-scale polygeneration systems in particular, due to the large capital cost which often discourages the adoption of CHP solutions both for the conversion of existing conventional plants and for new plants. Among the examined factors, this could seem the hardest to be quantified; however the experience indicates the presence of a high number of small-scale CHP applications as the best basis for a positive approach to polygeneration. Then, the most comprehensive definition of a parameter expressing this "cultural" factor can be given in terms of ratio between installed small-scale CHP capacity and the estimated potential for polygeneration in the building sector:

$$KH_{CHP} = 0.7 + \frac{1}{2.36} \cdot \frac{C_{s-s\,CHP}}{TC_{build.}} \cdot \left[5e^{\left(1\text{-}5 \cdot \frac{C_{s-s\,CHP}}{TC_{build.}}\right)} - 1.7 \right]. \tag{4}$$

The parameter KH_{CHP} is dimensionless. In its expression all coefficients were determined in order to achieve a suitable behaviour of the parameter, which varies in the range [0.7–1]; the expression between square brackets was introduced to take into account the market-saturation effects.

3.2. *Non- quantifiable factors*

In this sub-section different factors influencing CHP are presented, which cannot be easily quantified or have an ambiguous the relation with the potential for small-scale CHP.

However, in order to introduce such factors in the explicit definition of the gauge, an hypothesis on their impact on the CHP market must be made; hence, for each of the non-quantifiable elements a multiplying factor is given, expressing the expected increase or decrease that it provokes to the CHP potential (for instance, a 1.3 factor is equivalent to an estimated 30% boost effect on the CHP market).

1. *Liberalization of energy market*: the stagnation of CHP all over Europe and the ongoing liberalization of energy markets have opened a heavy debate on whether the liberalization gives a positive or negative contribution to CHP growth. In theory liberalization should provide new opportunities for cogeneration, through the elimination of many barriers deriving from a monopolistic structure of the electricity market which resulted in low tariffs for the purchase of surplus electricity, high tariffs for stand-by periods and no possibility of wheeling. Actually, in the Member States where liberalization have produced a significant fall in energy price, CHP has become less and less competitive; in fact, the free market is often environmentally distorted for the lack of monetary mechanisms supporting clean technologies, and the old big coal or nuclear power plants, whose capital investment is totally amortized, exploit their lower variable cost and grow in competitiveness. This controversial relation between liberalization and CHP potential induced us to define an articulated liberalization and CHP potential induced us to define an articulated parameter, which is:

$$MK_{lib} = 1 + \frac{1}{4} \cdot \left(L_{\%} \cdot \Pi_{env} \right) \cdot DP \tag{5}$$

where:

$L_{\%}$ represents the extent of market opening (depending on the number of large electricity producers and on the percentage of costumers eligible to purchase energy on the free market). Values in the range [0–1] are assigned;

Π_{env} indicates at what extent in the growing liberalized market reflects the efficiency and the environmental implications, creating insuperable barriers for low-cost but obsolete power plants. Its value varies in the range [-1–1];

DP this coefficient is introduced to consider the advantages for CHP systems over the ordinary demand-supply balance system of the free market, in the countries where a dispatching priority exists for CHP electricity (as allowed by Directive 2004/8/EC). DP assumes the value 1.1 in countries where a dispatching priority was introduced, and 1 where no.

By introducing the coefficient ¼ we expressed the estimation for a maximum 25% increase/decrease of the CHP potential due to the effects of the liberalization of energy market. The values assumed by $L_{\%}$ are derived from the results of several investigations available in literature [6–8];

2. *Grants and loans*: a relevant contribute to the economic viability of CHP/CHCP systems often derives from monetary support mechanisms not influencing the energy price, and thus not included among those examined in section 3.1. In particular we refer to public grants, which are usually expressed as a percentage of the capital cost, and soft loans at favorable recovery rates and reimbursement plan. This factor could seem easily quantifiable; however, in most cases the financial contributes have a very

articulated structure, and it is not easy to assess to which extent any small-scale CHP application could be supported. A parameter is introduced to keep account of financial support, indicated as Ω_{grant}. Where a clear pattern for grants exists, these are taken into account by a direct calculation of Ω_{grant} (a public funding accounting for 40% of the capital cost leads us to assume a 1.4 factor); otherwise, its values is based on an estimation of the contribute to the spread of small-scale CHP. Values higher or equal to 1 are obviously expected;

3. *Bureaucratic barriers*: the presence of a long and controversial process to obtain the required licenses for the auto-production of energy and for the connection to the grid, as well as the lack of transparent criteria for the access represent significant obstacle for the spread of small-scale polygeneration systems. The collection of detailed informations about the difficulties encountered by private or public customers before operating a CHP system is not an easy task; in this paper the results of many investigations are used, based both on a brief analysis of the licensing procedure in different countries and on informations about the complexity of these procedures as perceived at market-operators level. Again, the factor is quantitatively expressed by a dimensionless parameter, Ξ_{bur}, ranging from 0.5 to 1 (the higher Ξ_{bur}, the lower is the barrier to the spread of small-scale CHP represented by the licensing and grid-connecting procedure). The 0.5 value (50% percent reduction in CHP potential due to the bureaucratic-normative obstacles) was assumed as minimum value for countries where energy surplus could not be sold to the public grid; however, power selling is not prohibited in any of the examined countries, and the adopted values for Ξ_{bur} in all cases exceeded 0.7;
4. *Uncertainty at normative level*: the legislative framework about cogeneration has been rapidly changing, and further provisions are expected in the short-medium term, to be adopted both at EU and national level; on the other hand, project planning for power or thermal systems with a life-cycle in the order of 12–15 years need a stable and clear normative context. Hence, the lack of a reliable normative scenario for the medium-long term represents an obstacle for the spread of small-scale CHP, and in some countries it emerges as a decisive factor. A parameter is introduced to keep into account this factor, Θ, to be used as a multiplying factor in the expression of a synthetic indicator; as most of provisions will be adopted in an harmonized framework at EU level, the value of Θ slightly changes by country, varying from 0.7 to 0.9 (respectively corresponding to 30% and 10% esteemed impact on the potential for small-scale CHP);
5. *Connection and transport cost*: decentralized power production in small-scale systems reduces the need for long distance power flows by more local balancing of demand and supply; it is generally recognized that the way these avoided cost and advantages are reflected in the connection and transport fees will strongly influence the economics of cogeneration units. The EU Commission indicated that “the system of regulated Third Party Access on the basis of published prices is the method of permitting access to the network that will produce the most effective competitive

market”. A controversial argument concerns the transport fees system; in fact a multitude of systems have been working in different countries, like the “stamp” system, the “counter trade”, the “tariffs per zones” and the “point” systems. However, it is widely recognized that any system cannot be considered as favorable or detrimental for itself, and the effects on the decentralized production market primarily depends on the way it is actually implemented. The connection of CHP auto-producers with the grid is related to both the transparency of conditions for the connection and the setting of fair access criteria, from an economic viewpoint. As concerns the transparency, the electricity Directive 2003/54/EC (repealing the former 96/92/EC) only obliges the companies to maintain separate accounts of their production, transport and distribution activity; this was revealed to be a weak provision. Again, this factor is kept into account by introducing a parameter, $\Lambda_{c\text{-}t}$, which varies in the range 0.8–1 growing with the fairness of the system for the determination of transport and connection costs.

3.3. *An expression for the indicator assessing the potential of small-scale CHP/CHCP*

In the previous sub-sections the elements were presented, which will be considered in the definition of an indicator to assess the potential of small-scale CHP/CHCP in the tertiary sector. According with the contribute of each of the defined parameters, the proposed expression is as follows:

$$\Psi = S_{spread} \cdot \alpha_{Sp-spread} \cdot TDD_{eq} \cdot KH_{CHP} \cdot MK_{lib} \cdot \Omega_{grant} \cdot \Xi_{bur} \cdot \Theta \cdot \Lambda_{c-t} . \quad (6)$$

The defined parameter is obviously dimensionless; the potential penetration for small-scale CHP in the j-th country can be expressed as:

$$PP_{CHP,j} = RP_{CHP} \cdot \Psi_j , \quad (7)$$

where RP_{CHP} is the penetration in the assumed reference scenario; according to the definition of each of the parameters in Eq. 6, RP_{CHP} is the potential for small-scale CHP in a temperate climate country (like Italy, with TDD_{eq}=1), where:

- No inner advantages or disadvantage exists for the production of electricity by CHP systems (S_{Spread}=1);
- No monetary support mechanisms are working ($\alpha_{Spark\text{-}spread}$=1);
- CHP covers the 10% of the total installed capacity in the tertiary sector ,which was assumed as the best penetration share as concerns the factor indicated as CHP knowledge (KH_{CHP} = 1);
- The degree of market opening, the environment-oriented provisions and the eventual dispatching priority for CHP electricity make liberalization not to empower nor to weaken the spontaneous trend of growth of small-scale polygeneration (MK_{lib}=1);
- No financial support mechanisms exist for starting CHP applications (Ω_{grant});
- No bureaucratic barriers exist (Ξ_{bur}=1);

- A clear and stable normative framework exists, as concerns small-scale CHP/CHCP systems (Θ=1);
- The connection and transport cost properly reflect the inner advantages of decentralized production systems and the benefits produced for the overall grid balance (Λ_{c-t}=1).

Obviously, two different Ψ_p and Ψ_s values were obtained, respectively for power purchasing and selling. Both these values provide information on the feasibility of small-scale CHP/CHCP for application in buildings; however, the adoption of two distinct values allows to recognize whether the spread of polygeneration systems oriented to base load production or to energy selling could be expected.

The philosophy adopted for the definition of the above gauge shows the dynamic-decisional purposes of the indicator; independently from the actual penetration of small-scale CHP in a country, it allows to predict the effectiveness of any policy that could be implemented through an analysis of the single elements on the right-hand member of Eq. 6. In the next section a brief analysis for six European countries is presented, oriented to the determination of the parameters introduced in this section; the analysis furnishes basic instruments for a successive analysis of policy actions that could be undertaken.

4. Results

The parameters defined in the section three were calculated for different European countries, and in this section the results are presented.

A very inhomogeneous set of countries was selected (composed by the countries indicated in Figure 2), with the purpose to furnish a valid basis for an analysis of the achieved results.

In Figure 3 the values of the indicator Ψ is represented, in two distinct series for energy purchasing and energy selling modes.

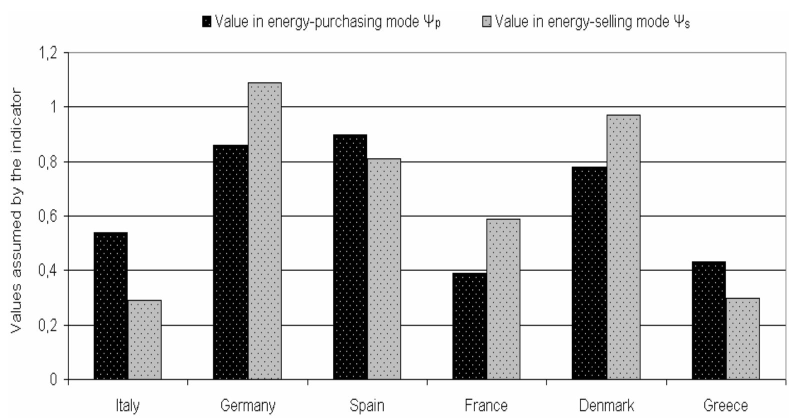

Figure 3. Values assumed by the defined indicator in energy-purchasing and energy-selling periods, per country.

5. Conclusions

An original indicator for the assessment of the potential small scale CHP market in different countries was proposed, which is based on a set of factors most influencing the spread of polygeneration systems.

The impact of each factor was expressed in analytic terms, with a distinction among quantifiable and non-quantifiable factors; the second group of factors is kept into account by introducing esteemed expressions for the market effects.

After collecting a sufficient set of data, the values assumed by the indicator was calculated in six European countries, distinguishing between the energy-purchasing and the energy-selling mode.

Reasonable values were obtained, which reflects sufficiently the current trend of national small-scale CHP markets in the examined countries. The proposed method is very flexible and suitable for adjustments depending on peculiar aspects of the energy market and on different definition of the set of factors.

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MATHEMATICAL MODELING OF A HEATING SYSTEM FOR A SnO_2 CVD REACTOR AND COMPUTATIONAL FLUID DYNAMICS SIMULATIONS (3D-CFD)

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This paper presents the study of the heat transfer of a continuous system that is being designed for the deposition of tin oxide thin SnO_2 films on soda-lime glass substrates of large dimensions (400 mm x 400 mm x 2 mm) in terms of Liquid Crystal Displays (LCD) glasses production improvement. This system will operate with infra-red heating (parallel mounted ceramics IR lamps in one unit) and will substitute the present CVD system, which is used in the CenPRA display pilot plant to coat substrates up to 150 mm x 150 mm x 2mm. In this system the substrates are heated by thermal conduction and the deposition is done by a ´´in house´´ process called Vapor Decomposition Process (VDP). Using numerical solver FLUENT, simulated was VDP process at atmospheric pressure, taking in mind that the system consists of two parallelepiped-like chambers: the furnace containing the IR lamps in which the glass is heated, and the chamber where the deposition occurs. FLUENT helps us to obtain the resolution of the elementary differential equations for mass diffusivity, full multi-component thermal diffusion effects and reactions on the heated substrate. The simulations permitted to get a 3D perspective of the deposited layer along the substrate surface and also to calculate the VDP process parameters as temperature, pressure, reaction rate for each species (O_2, Cl and HCl) and gas speed along the chamber.

1 Introduction

Brazil, the land of an internal sun! How to help the Brazilian population to increase energy efficiency by decreasing heat load of household air condition systems? The answer is INTELIGENT WINDOWS and it was given by CenPRA.

The CenPRA (Centro de Pesquisas Renato Archer) is an acronym for the major federal researching institute for microelectronics located in Campinas, Sao Paulo, Brazil. It is sponsored mainly from a government budget and therefore very often seeks the money for the investments of the necessary researching equipment. By help of young students they try to invent and design all necessary stuffs for the experiments.

† The author had developed the model during the student internship in Brazil.

During my 7th months stay in CenPRA on internship, I was enrolled into department for developing equipment and process improvement of the Liquid Crystal Displays.
There was existing old equipment for step-by-step producing of semi-conductive thin layers of $_{SnO2}$ on glass surfaces obtained with Chemical Vapor Deposition (CVD) of the gasses ($SnCl_4$, $_{H2O}$). Furthermore, those glasses were mounted into ‘sandwiches’ due to obtain semi-conductive polarized transparent layers. Connecting on those deposited glasses a microcontroller we will obtain intelligent window which will be used for reducing of income sun beams through the windows into houses.
Topic of the project was to invent, design and realize the new plant for continuously producing (substrate placed on moving belt which will first pass through the furnace and after while through the depositing chamber), by the deposition, of tin oxide thin films on soda-lime glass substrates of large dimensions (400 mm x 400 mm x 2 mm).

2 Approach to the problem

Basically, I was confronted with studying of Chemical Vapor Deposition in general. Theory says that CVD process is feasible under the following conditions: soda lime glass (400x400x2 mm) has to be preheated up to approximately 400ºC and after heating is prepared to be deposited under atmospheric pressure (p=101325 Pa) by gas mixture of $SnCl_4 + 2H_2O$ in depositing chamber. It was from crucial significance to determine the time necessary for heating of the soda lime glass substrate. Using that time it was possible to calculate constant velocity for moving belt on which was substrate placed. Finally it has had to be synchronized time which glass spent under the infra red radiators - furnace and in depositing chamber due to constant velocity of moving belt.
The main idea of problem simplification was to split CVD into two parts: heating and deposition. In first part of problem determination was modeled time necessary for heating of the substrate and in second part occurred 3D Compotation Fluid Dynamics (CFD) simulations. Due to small velocity of moving belt, there appeared some assumptions. There were ignored boundary conditions in heating process on the edges of the glass substrate:
Dispersion of infra red beams – energy lost.
Non uniform heated surface – bad pattern for the intelligent window.
Length of substrate caught by deposition chamber after furnace is on constant temperature during deposition.
The system consists of two parallelepiped–like chambers: the furnace containing the IR lamps in which the glass is heated (1) and the chamber where the deposition occurs. In the chamber (1) is used a mathematical model for determining the necessary time for heating the substrate with IR radiators, while in chamber (2) are made 3D simulations of the CVD process.
Basic chemical reaction which occurs on soda lime glass surface is given below:

$$SnCl_4 + 2H_2O \rightarrow 4HCl + SnO_2. \tag{1}$$

Tin chloride $SnCl_4$ appears in gas phase and H_2O appears like water vapor. SnO_2 tin dioxide is finally wanted product of deposited semi –conductive layer and there is also unwanted product of hydrogen chloride which has to be safely removed from depositing chamber.

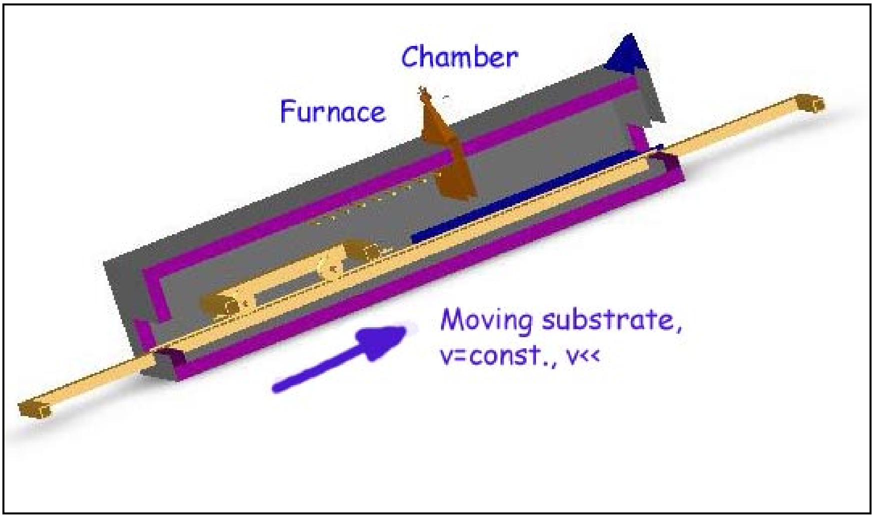

Figure 1. Illustration of the heating system (furnace) and the deposition chamber for the continuous LCD production.

3 Mathematical model of the heating system with IR-radiators

Adopted was “two parallel plates” model for radiation due to nearness of IR radiator surface and soda lime glass surface which is also explained in Figure 2. Infra red radiators IR were considered like a heating plane surface of a constant temperature 900ºC.

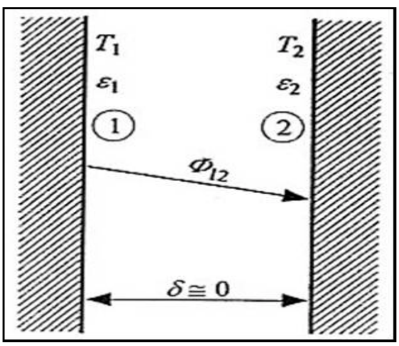

Figure 2. Description of the applied radiation model.

Basic equation for the heat flow from the IR’s to the substrate:

$$\Delta\Theta_{12} = mc\frac{\Delta T}{t}. \tag{2}$$

The heat flow is given by the equation for radiation between two flat surfaces:

$$\Delta\Theta_{12} = \frac{A\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}. \tag{3}$$

By equalizing these equations and transferring into infinitesimal form:

$$\rho\delta c \frac{dT}{dt} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}. \tag{4}$$

Final form of the basic integral equation for this system is given by Eq. (5):

$$T = \frac{\sigma}{\rho\delta c\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)} \int_{t=0}^{t=t_1} \left(T_1^4 - T_2^4\right) dt\,. \tag{5}$$

Solving that equation from t = 0 up to 150 s time depended substrate temperature is shown below (Figure 3).

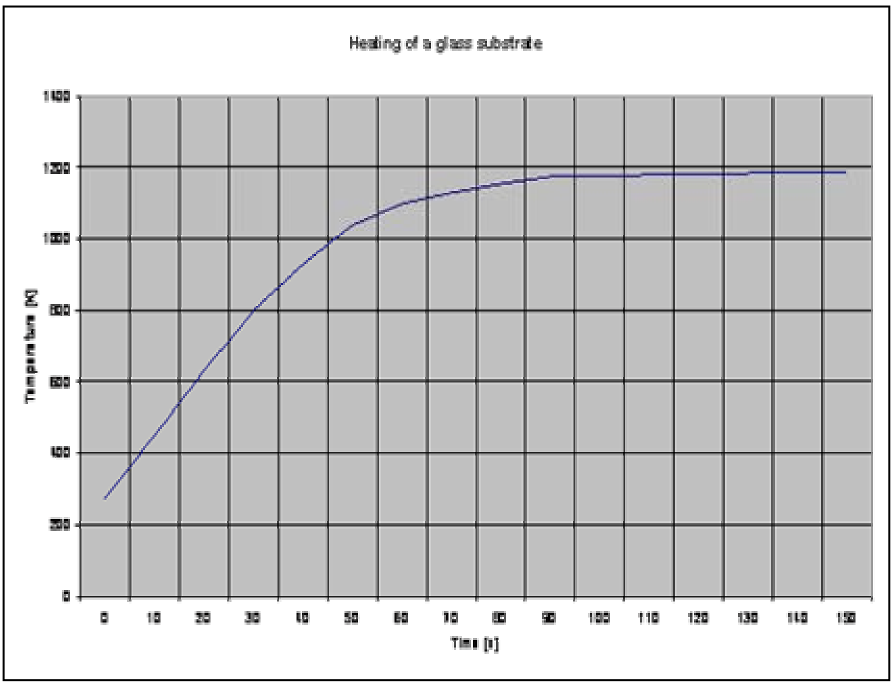

Figure 3. Soda – lime glass heating curve.

According to our model it is necessary to heat the substrate for approximately 23 s to achieve 400ºC (soda-lime glass 2 mm thick), which is supposed to be an optimal temperature for Chemical Vapor Deposition.

4 3D-CFD simulations of CVD process

Chemical Vapor Deposition (CVD) is complex process which at the same time includes accurate modeling of time - dependent hydrodynamics, heat and mass transfer and chemical reactions (including wall surface reactions).
Modeling the reactions taking place at gas-solid interfaces is complex and involves several elementary physico-chemical processes like adsorption of gas-phase species on the surface, chemical reactions occurring on the surface and desorption of gasses from the surface back to the gas phase.

Methodology

- Creating basic geometry in Gambit.
- Splitting real, finite, volume into infinite derivable ´´control volumes´´, ´´meshing´´.
- Defining boundary zones (inlet, outlet, surface and wall).
- Exporting designed model into solver Fluent where the final model definitions occurred.
- Applying numerically algorithm for solving system of differential equations assuming a priori values for temperature, velocity, pressure, surface deposition ratio and correcting them in each iteration.
- The system of equations is solved when the final difference, called ´´Residual´´, between obtained results and input boundary condition is smaller then initial value given by user.

Differential equation system

Continuity equation:

$$\frac{\partial \rho}{\partial t} = -\frac{\partial(\rho v_j)}{\partial x_j} \tag{6}$$

Momentum conservation equations:

$$\frac{\partial(\rho v_i)}{\partial t} = -\frac{\partial(\rho v_j v_i)}{\partial x_j} + \rho f_i - \frac{\partial p}{\partial x_i} + \frac{\partial \sum_{ji}}{\partial x_j} \tag{7}$$

Energy conservation equation:

$$\frac{\partial}{\partial t}\left[\rho\left(\frac{v^2}{2}+u\right)\right] = -\frac{\partial}{\partial x_j}\left[\rho v_j\left(\frac{v^2}{2}+u\right)\right] + \rho f_i v_i - \frac{\delta(p v_i)}{\partial x_i} + \frac{\partial\left(\sum_{ji} v_i\right)}{\partial x_j} + \frac{\partial}{\partial x_i}\left(\lambda\frac{\partial T}{\partial x_i}\right) \tag{8}$$

Eqs. (6)-(8) define only mass and heat transfer of the gasses along the chamber while Eq. (9) presents conservation species transport equation:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \cdot (\rho \vec{v} Y_i) = -\nabla \cdot \vec{J}_i + R_i + S_i, \tag{9}$$

where below is given explanation for each symbol in equation: Y_i - the local mass fraction of each species; R_i - the net rate of production of species i by chemical reaction, S_i - the rate of creation by addition from the dispersed phase plus any user-defined sources and $\vec{J}_i$ - is the diffusion flux of species i.

4.1. *Problem definition for model No.1*

As is it shown in Figure 4 the observed control volume of deposition chamber consists of following significant surfaces: inlet, reactant and outlet surfaces. The mixture of reactant gasses, $SnCl_4 + 2H_2O$, flows into deposit chamber, react on heated reactant surface and goes out through the outlet surface. Model assumption which was applied is that temperature of the reactant surface is constant along the width of the chamber and for first simulation that velocity of reactant surface is 0.
The big significance in this researching work was determination of the material properties of an exotic chemical species and reactions.

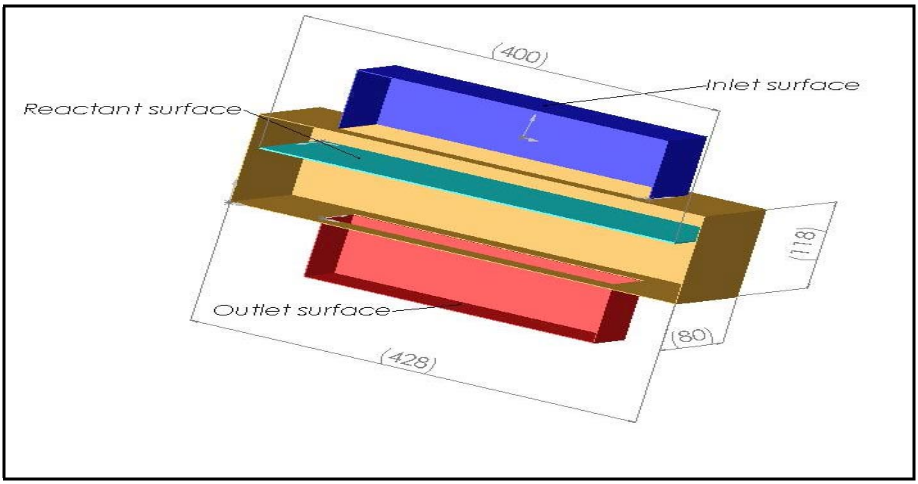

Figure 4. Design of the deposition chamber – Model 1.

4.1.1. *Results of model No.1*

Thanks to excellent graphic user interface of Fluent, interpretation of obtained results was quite easy in colorized 3D perspective. From Figure 5 we can see that red color present biggest surface deposition rate of SnO^2 expressed in (kg/m^2-s). That was expected data due to biggest concentration of species mixture on reactant surface edge where the gases bypass the surface according to the outlet surface.

Table 1. The material properties of chemical species and reactions.

Parameter	***HCl***	***$SnCl_4$***	***SnO_2***
Name	Hydrogen-Chloride	Stannic-Chloride	Stannic-Oxide
Density (kg/m^3)	1.5599	2234	6930
Cp (J/kgK)	0.00798	0.6345	0.3489
Thermal conductivity (W/mK)	0.0159	66.8	93.1295
Viscosity (kg/ms)	1.31e-05	0.00095	0.0075
Molecular weight (kg/kmol)	36.461	260.51	150.71
Standard state enthalpy (J/kg)	-5.7763e+08	-5.113e+08	-5.7763e+08
Standard state entropy (J/kgK)	186900	250600	49040
Reference temperature (K)	298.15	298.15	298.15
L-J characteristic length	3.711	3.711	3.711
L-J energy parameter	78.6	78.6	78.6
Degrees of freedom	0	0	0

Reference:
"Handbook of Chemistry and Physics, 77th Edition", David R.Lide 1996-1997

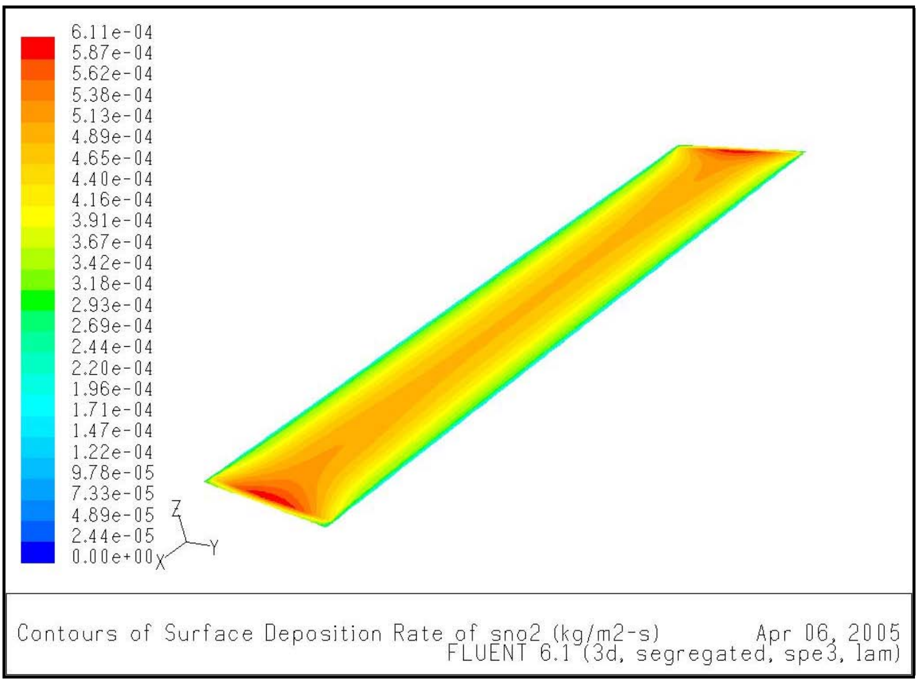

Figure 5. SnO_2 deposition among the soda - lime glass for the model No. 1.

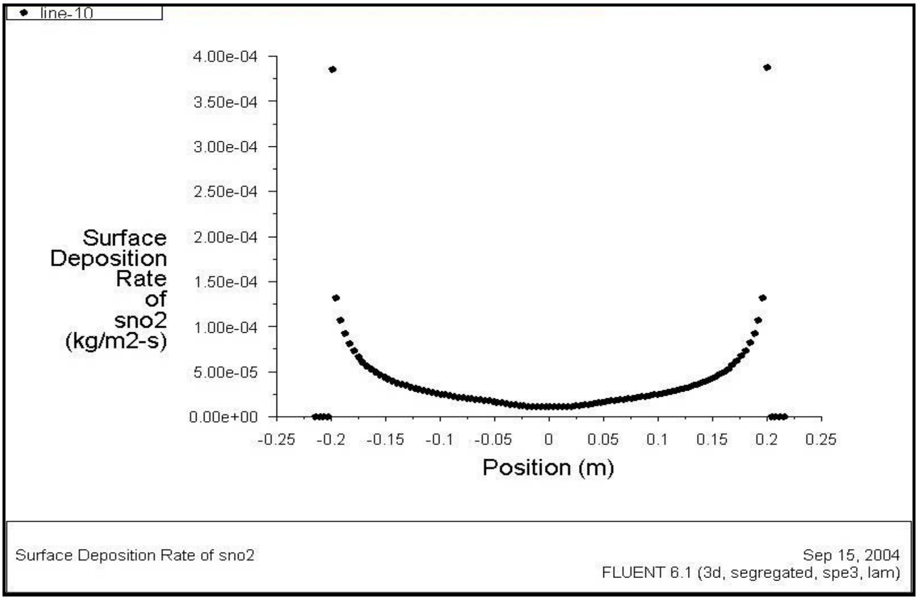

Figure 6. 2D chart of surface deposition rate along the center line of the reactant surface.

As we can see, surface deposition rate of SnO_2 along the substrate surface is not uniform 'enough' (deposition curve should be flat, not parabolic shaped). Main significance of siis to obtain as much as it is possible uniform deposited layer along the soda - lime glass substrate. Therefore, depositing chamber model geometry and positioning of observed surfaces improvement should occur!

4.2. *Problem definition for model No. 2*

Basic idea to change chamber construction was to redirect gases flux above the substrate surface in transversal direction instead of old, vertical and width of substrate is in total caught by gases inlet so there is avoided possibility of local gases concentration in some boundary areas above the substrate.

4.2.1. *Results of model No2*

From Figure 8 we can see that geometry redesign was helpful in terms of deposition uniformity improvement. On coordination defined with vector (x {0.0025-0.403}, y=0.04, z=0.0222), where is the most red color, obtained was uniform deposition along the substrate width. Wanted aim of deposition uniformity was provided!

According to initial data from table 2, 2D chart of surface deposition rate is presented in Figure 9.

For final simulation was again decreased velocity of moving substrate which just justified better deposition rate of SnO_2 along the soda lime –glass substrate.

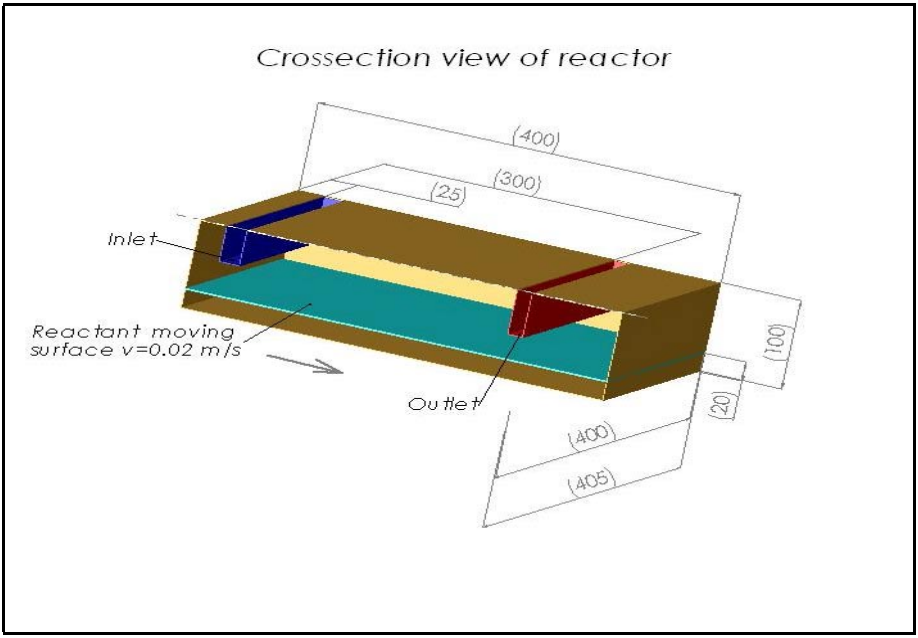

Figure 7. Design of the deposition chamber – Model No. 2.

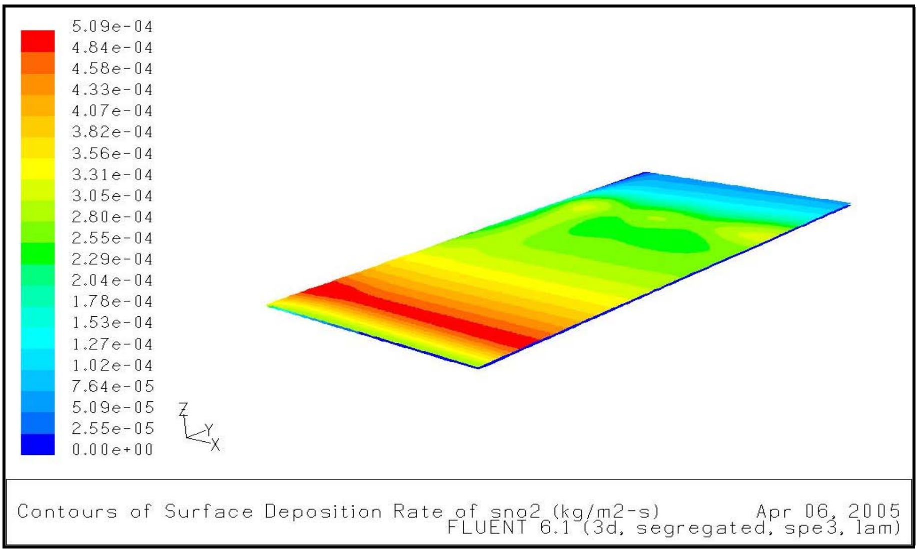

Figure 8. SnO_2 deposition among the soda - lime glass for the model No. 2.

Table 2. Operating and boundary conditions for the first iteration.

Operating conditions		Boundary conditions INLET				Boundary conditions SURFACE		Boundary Con. OUTLET
				Mass fractions				
p (Pa)	T (K)	v (m/s)	T (K)	$SnCl_4$	H_2O	T (K)	v_y (m/s)	Outflow
100000	303	0.08	573	0.4	0.3	673	-0.05	

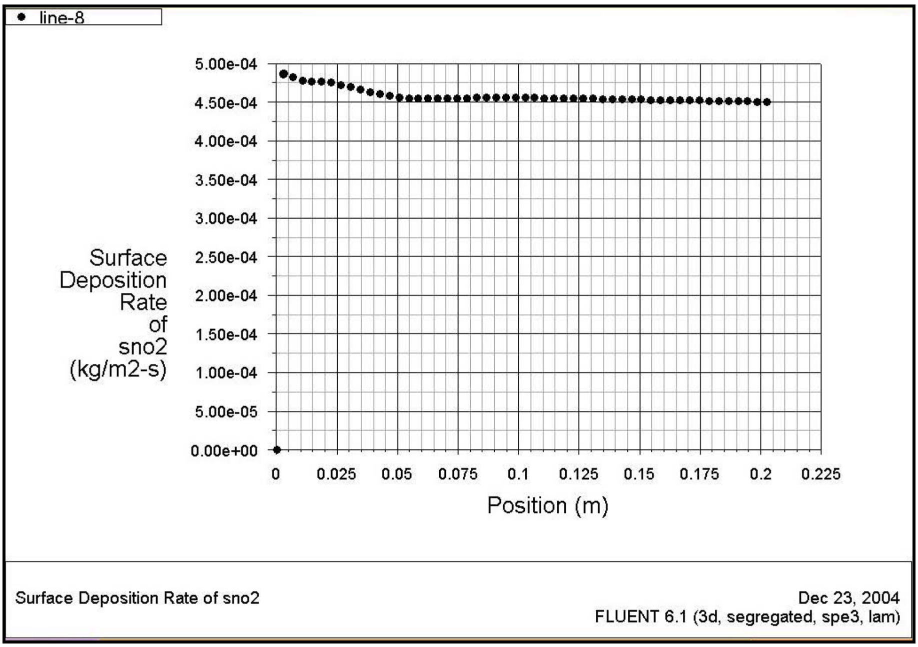

Figure 9. 2D Chart of SnO_2 layer along the line defined with (x {0.0025-0.403}, y=0.04, z=0.0222).

Table 3. Operating and boundary conditions for the last iteration.

Operating conditions		Boundary conditions INLET				Boundary conditions SURFACE		Boundary Con. OUTLET
				Mass fractions				
p (Pa)	T (K)	v (m/s)	T (K)	$SnCl_4$	H_2O	T (K)	v_y (m/s)	Outflow
100000	303	0.08	**403**	0.4	0.3	673	**-0.12**	

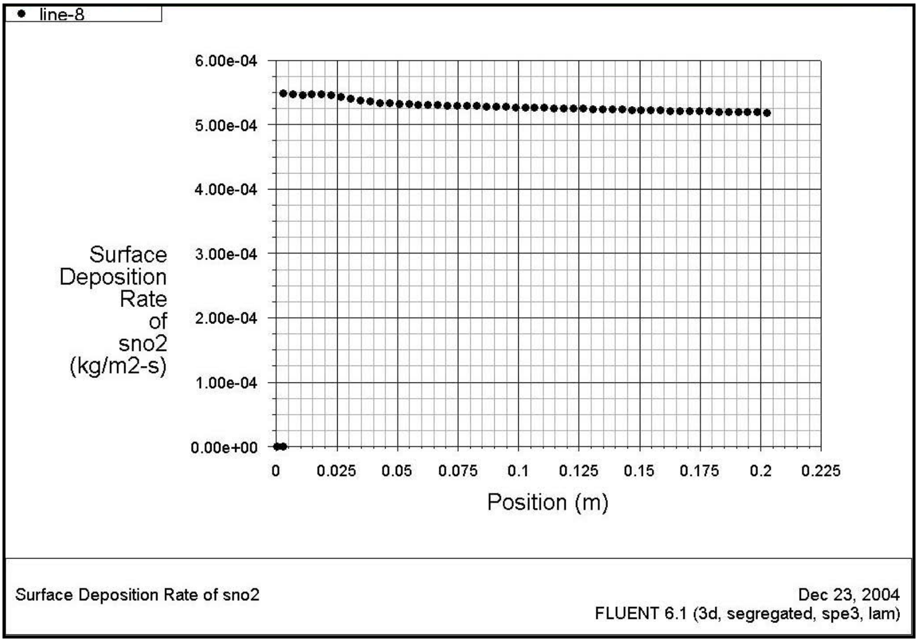

Figure 10. 2D Chart of SnO_2 layer along the line defined with (x{0.0025-0.403}, y=0.04, z=0.0222).

5. Conclusion

Although it was used very simple chamber geometry, the simulation showed to be helpful if we intend to optimize the uniformity of the deposited layer, throughput and the yield of the coating glasses of large area. Further research will be focused on improving geometry of the chamber and optimizing parameters of the process to get better uniformity of the deposited layer along the substrate surface. Enhancement of the model could occur also by modeling of inlet nozzles which were out of time for this project.

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WATER MANAGEMENT

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THE WATER FRAMEWORK DIRECTIVE AND MEDITERRANEAN AGRICULTURE

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The high irrigation demand for water resources in Mediterranean countries, creates significant water quality problems compounded by water scarcity. The reliance of the Water Framework Directive on water pricing to solve water scarcity or improve water quality, may fail in Mediterranean countries. Therefore, other Directive instruments need to be applied, such as control on aquifer abstractions, ambient quality standards and emissions limits. These instruments require knowledge on local biophysical processes and ecosystem damage costs that are far from available at present.

1 Introduction

Irrigated agriculture in Mediterranean countries is an essential factor for agricultural production, while irrigation water is used only marginally in central and northern European agriculture. There is a significant pressure on water resources and fluvial ecosystems in Portugal and Greece, because of the large share of water extractions for irrigation. However the pressure on water resources is much more important in Spain, Italy and Turkey because of the very large acreage under irrigation, with a combined water demand close to 80.000 hm^3 (Table 1). Irrigation development in these three countries has been driven by large and sustained public investments in waterworks to store, transport and distribute water to irrigation fields.

Another aspect to consider in the case of Italy and Spain, is the development of groundwater extractions in the second half of the twentieth century. The large escalation in groundwater extractions has been driven by the falling costs of pumping technologies in areas with profitable irrigated crops. In contrast to the large collective irrigation systems, these private groundwater extractions are not subject to much control by the water administration.

In Italy, pervasive aquifer overdraft and water quality problems are located in the Po basin, Romagna and Puglia, and in the coastal plains of Campania, Calabria and Sardegna. In Spain, the most severe scarcity and quality problems occur in the Júcar, Segura and South basins, located in the southeastern Iberian peninsula.

The consequence is that there is a dual situation for water resources linked to irrigation. The irrigation districts of inland Spain and southern Italy are based on collective surface irrigation systems and low profit crops, and water resources degradation is moderate.

Table 1. European countries with large water use for irrigation (2001).

Country	Total water extractions (hm^3)	Irrigated land (1000 ha)	Irrigation water (hm^3)
Germany	40360	490	620
United Kingdom	15890	110	1900
France	29820	2200	3120
Greece	8910	1450	7700
Italy	56200	2700	25850
Portugal	9880	650	8770
Spain	26050	3650	21340
Bulgaria	5830	800	870
Hungary	5590	210	500
Poland	11600	100	1030
Romania	7340	2670	1020
Turkey	39780	4500	31000
Total Europe	291870	21170	109470

Source: EEA (2005) [6].

The reason is that basin authorities regulate water extractions, and there is some degree of fluvial ecosystem protection by the enforcement of minimum ecological flows. High profitable Mediterranean crops such as fruits and vegetables concentrate in the coastal areas of Spain and Italy, which are based on individual pumping from aquifers.

There are two general policy approaches when dealing with quantity and quality problems faced by Mediterranean irrigated agriculture. One is the traditional water policy approach based on expanding water supply, and the other is the new emerging approach based on water management initiatives. These emerging initiatives rely on measures such water pricing, revision of water rights, abstraction limits on surface and subsurface waters, development of regulated water markets, and water resources reuse and regeneration. These management initiatives are better suited to solve irrigation scarcity than new supply technologies such as desalination [7].

A very illustrative example of the conflict between these two approaches, is the type of solutions that have been considered for solving water scarcity and degradation in southeastern Spain. Two projects have been presented in the last four years; the Ebro interbasin transfer and the new AGUA project designed to substitute for the Ebro transfer. Both projects rely on the traditional approach of expanding supply with subsidized public investments, and both are questionable on economic grounds.

However, new water management approach measures should be applied carefully and need a reliable information base. The example presented here deals with agricultural nonpoint pollution, and shows that nonpoint pollution control instruments cannot be assessed accurately without a correct understanding of the key underlying biophysical processes. Neglect of these processes may lead to wrong policy measures.

This paper examines quantity and quality issues of Mediterranean irrigated agriculture, presenting empirical evidence from Spain on alternative policy options and measures. Along the lines of the European Water Framework Directive, the measures examined cover two cases: the evaluation of alternatives to solve water scarcity in southeastern Spanish basins, and ranking agricultural pollution control instruments by their cost efficiency.

2 The Water Framework Directive and Mediterranean irrigated agriculture

The European Union has approved the Water Framework Directive to protect all continental, coastal and subsurface waters. The Directive objectives are the improvement of water quality and ecosystems conditions, the promotion of sustainable use of water, and the reduction of emissions and discharges to water media. The economic aspects of the Directive are addressed in article [5] (economics analysis of water use), article [9] (cost recovery) and article [11] (programme of measures). Water pricing should approximate full recovery costs to increase water use efficiency, by including extraction, distribution and treatment costs, environmental costs and resource value costs. There are also a combination of emission limits and water quality standards, with deadlines to achieve good status for all waters.

The European Water Directive has a great potential to solve water scarcity and nonpoint pollution in Mediterranean countries, and this initiative is supported by the findings of the European Environmental Agency, which point to agricultural nonpoint pollution as the primary cause of water quality deterioration in many European watersheds [5]. However, the reliance of the Directive on water pricing to curb demand may fail in Mediterranean countries such as Spain and Italy, with high irrigation demand and quality problems compounded by water scarcity.

Water pricing will not solve scarcity or improve quality in the more degraded areas, because rising water prices would reduce consumption in large irrigation districts of inland Spain or southern Italy, based on collective systems and low-profit crops, where degradation problems are moderate. But water demand will not respond to higher prices in areas based on individual aquifer extractions with Mediterranean high-profit crops, where pressure on water resources is pervasive and degradation is severe [12].

Water pricing fails as a workable policy for curbing irrigation demand for several reasons. The first is that, after decades of mismanagement, the number of illegal private wells is huge and there is no control over the volume pumped from either legal or illegal wells. The consequence is that it is almost impossible to implement a tax on water pumped from aquifers. A second reason is related to the water price level that is needed to curb demand. In Spain, shadow prices of water in coastal areas under greenhouse production can reach three to five euros per cubic meter, against 10-20 cents €/m^3 in inland Spain, while current water prices in coastal areas are between 6 and 21 cents €/m^3 compared to 2-5 cents €/m^3 in inland collective irrigation systems [3, 4]. With urban prices in Spain close to or below one euro per cubic meter, and seawater desalination at around 50 cents €/m^3, it would seem unacceptable to set agricultural prices in water scarcity areas above urban and desalination prices. Though a policy designed to control aquifer overdraft would be quite difficult to implement, a water pricing policy that were to drive prices above the three to five euros shadow price per cubic meter for private extractions would be impossible to implement, both because of its technical and administrative unfeasibility and the daunting prospect of social opposition from farmers. These more degraded areas therefore require other Directive instruments, such as controlling aquifer overdraft by reducing concessions, and enforcing ambient quality standards and pollution emissions limits.

These facts seem to indicate that the Water Framework Directive would be difficult to implement in Mediterranean countries. The question is the following, a water pricing policy can be implemented easily at least in collective irrigation systems managed by the basin water authorities, but instruments to control aquifer extractions, pollution emissions and ambient quality are much more difficult to implement. The information needed by policy decision makers on aquifers recharge and pumping by farmers, irrigation pollution emissions from either surface or subsurface water, soils, pollutant transport and fate processes, ambient pollution, and damage costs to ecosystems, is not available in countries with significant irrigated agriculture such as Spain, Italy, Portugal and Greece. Without this information base, it is impossible to design reasonable control measures to prevent aquifer overdraft and abate nonpoint pollution. The consequence is that water pricing measures suited to reduce industrial and urban demand, which are paramount in northern and central European countries, would be implemented for irrigation in Mediterranean countries instead of the measures that are really needed.

Even under the now binding Water Framework Directive, policy developments in Spain show that the traditional approach of expanding water supply remains the essential scheme underlying water policy initiatives. The recent Ebro water transfer project and the new AGUA project, highlight the weaknesses of this traditional approach.

3 The rise and fall of the Ebro water transfer

The Ebro interbasin project was intended to solve the acute water scarcity and resource degradation of southeastern Spanish basins. The Ebro project nominal costs were close to 5 billion euro, transferring 800 hm^3 up to a distance of 750 km, from the Ebro basin to the Júcar, Segura and South basins of southeastern Spain. The Ebro transfer met with strong opposition from water resource experts, environmental and social organizations, and the Aragón and Cataluña regions located in the Ebro basin, and the main argument against the Ebro transfer was the need of new policy initiatives based on reasonable management measures.

A research effort was undertaken to evaluate alternatives to the Ebro water transfer. The evaluation is based on a model that incorporates a large quantity of technical and economic information specified at the county level. The model is used to simulate several water supply and demand policy scenarios, and details on the model building, parameter estimation procedures, and simulation results are presented in Albiac *et al.* [1, 2, 3, 4]. The study covers thirty five southeastern counties of the Iberian Peninsula receiving water from the Ebro transfer (Figure 1). The objective function maximizes quasi-rent from irrigated cultivation activities, and the constraints represent land, water and labor resource availability, considering irrigation acreage by type of crop, and monthly irrigation and labor.

The year of reference for all technical and economic data is 2001, and the baseline data on acreage, water use and revenue are presented in Table 2.

The costs of the Ebro project at each delivery location have been calculated by Uche [15]. The energy costs of pumping are an important cost component of the transfer project, and the specific energy consumption at each section is closely related to the channel's elevation. Costs of diverted water are lower than seawater desalination (0.52 €/m^3) up to the Tous outlet, but desalination costs beyond Tous are lower than transfer costs, and transfer costs in Almería double the desalination costs.

Table 2. Acreage, water use and revenue in southeastern basins (2001).

Basins	*Total*	*Cereals, alfalfa and sunfower*	*Fruit trees*	*Open air vegetables*	*Greenhouse vegetables*
Júcar					
Acreage (1,000 ha)	212.7	18.5	173.6	19.5	1.1
Irrigation water (hm^3)	1,450	242	1,081	121	6
Revenue (million €)	1,196	39	957	167	33
Segura					
Acreage (1,000 ha)	154.9	8.1	107.7	34.2	4.9
Irrigation water (hm^3)	863	62	654	125	22
Revenue (million €)	1,070	6	485	336	243
South					
Acreage (1,000 ha)	54.5	1.1	18.7	6.5	28.1
Irrigation water (hm^3)	232	10	96	24	102
Revenue (million €)	1,124	1	67	87	969

3.1. *Water management scenario*

The effects of several water management alternatives in the irrigated agriculture of southeastern basins have been analyzed. Two alternatives involve water demand management measures, two others are water supply expansion measures, and the last alternative is a combined management alternative. In the first scenario, a strategy is analyzed in which groundwater overdraft is forbidden, and there are no transfers of water from external basins. In the second scenario, a price increase is considered in order to find the price level that balances water demand with the available water resources in southeastern basins. This scenario follows the full recovery cost principle of the Water Framework Directive. The third alternative is to expand water supply with transferred water from the Ebro, linked to water subsidies to maintain the present low irrigation water prices. The fourth alternative combines water trading among counties with prohibition of aquifer overdraft.

Water trades may take place along present conveying facilities of main rivers and canals, allowing for additional supply of desalinated water. Desalinated water is considered in coastal counties that exhibit very high shadow prices of water. The elimination of aquifers overdraft reduces the availability of water for agriculture by 422 hm3, and the effects are concentrated in the counties where aquifers are located. In the

Júcar and Segura basins, the reduction of available water and cultivated acreage mainly affects low profit crops.

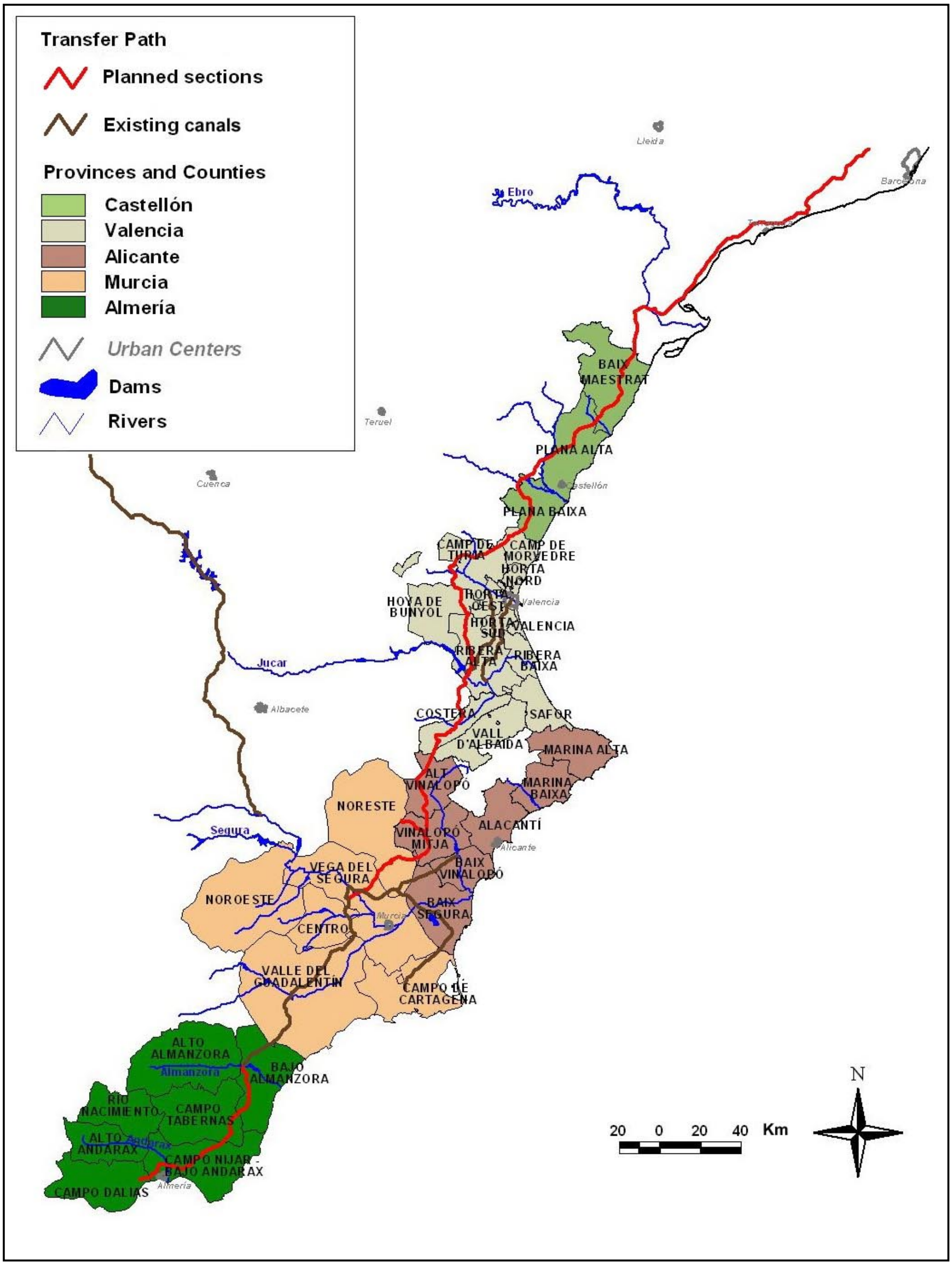

Figure 1. Map of the water transfer path and counties in the receiving basins.

Source: Trasagua (2003) for the latest water transfer path [14].

But in the South basin, the reduction of water and cultivated acreage affects highly profitable greenhouse crops, since there are few low profit crops to be given up (Table 2). Losses are quite substantial in the South where revenue and quasi-rent of farmers fall by almost 50 percent, while losses in Segura and Júcar are moderate.

The increase in water prices for irrigation is a demand management instrument advocated by the new Water Framework Directive. Agricultural water prices could be maintained below prices paid by other users, but scarcity in Southeast could be solved increasing prices by 0.12 €/m^3. A 0.12 €/m^3 increase in water prices reduces agricultural water demand by 509 hm^3, with a fall in farmers revenue and quasi-rent, due to the decline in the acreage of cereal and woody crops which are less profitable. The impact on quasi-rent is much greater in the Júcar and Segura basins than in Almería.

An increase of 0.18 €/m^3 in water prices reduces water demand by 605 hm^3, as a consequence of abandonment of cereal cultivation and reduction in cultivation of woody crops. The cost of this proposal to farmers is given by the decline in quasi-rent amounting to a sizeable 24 percent.

Desalination of seawater is a measure complementary to increasing water prices, that expands supply and balances water resources demand and supply in southeastern basins. The cost of desalination is 0.52 €/m^3 [15], and the effective water demand at this price in the coastal counties from Safor to Campo Dalías is 387 hm^3. Desalination cost is lower than the costs of transferred water in the counties south of Safor. Water supply and demand could be balanced by desalination coupled with an increase of 0.12 €/m^3 in water prices. Transferring water from the Ebro was the alternative of the National Hydrological Plan Law, that has been cancelled by the new Spanish government. Diverted water would have high costs which depend on the distance from the Ebro river [15], with a range of prices between 0.20 €/m^3 in Baix Maestrat county and 1.05 €/m^3 in Campo Dalías county. These prices are well above the low prices in the range 0.06-0.21 €/m^3 that farmers pay now, and at these prices the project water will only pay for itself in counties with highly profitable crops. The volume of imported water that counties can absorb at the prices shown in Table 3 is 761 hm^3 in Júcar, 294 hm^3 in Segura and 132 hm^3 in South. These quantities contrast with the planned water transfer targets for agricultural and environmental use of 141 hm^3 in Júcar, 362 hm^3 in Segura and 58 hm^3 in South. Thus, in the Segura basin there is a significant problem of inconsistency in the Ebro project, since this basin can only absorb 294 hm^3 of water destined to agricultural use at the water transfer price, which doesn't cover the Ebro project assignment of 362 hm^3 to end groundwater overdraft.

The former central Spanish government asserted that farmers in the receiving basins would pay for Ebro water the same price they are paying for water now. Therefore the central government was intending to resolve the inconsistency in transfer allocation targets by subsidizing the price of transferred water allocated to agriculture, and by charging higher prices to urban and industrial water users.

Finally an alternative combining both demand and supply measures is considered. This alternative combines banning groundwater overdraft, allowing water trades among counties, and supplying desalinated seawater to selected coastal counties. Water trades between counties occur along present conveying facilities of main rivers and canals, bringing water where most valued according to shadow prices of water in each county. Water shadow prices indicate that water transfers may occur along the Vinalopó, Segura (including Argos and Quipar tributaries), Guadalentín, Almanzora and Andarax rivers, and along the Canal Margen Izquierda and Canal Campo de Cartagena.

Results from the combined scenario show a significant reduction of 362 hm^3 in water use and moderate losses of 83 million € in quasi-rent (Tables 3 and 4). The gain in quasi-rent when moving between the banning overdraft (-408 mill. €) and the combined alternative (-83 mill. €) is 325 million €. This gain in welfare from water trading and desalination is measured by the economic surplus or area between water excess supply and excess demand functions in each county, so water trade and desalination flows are calculated by maximizing welfare.

3.2. *Ranking of water management alternatives*

The results from each water management alternative are summarized in Tables 3 and 4. Table 3 presents water demand scenarios under each alternative, and also the planned allocation of water of the Ebro project. Table 4 shows farmers' quasi-rent losses under each alternative, and therefore the subsidies needed in order to maintain farmers' quasi-rent. Farmers' quasi-rent losses are obtained by comparing the proposed alternative with the current situation. Quasi-rent is 1,711 million € under the present baseline scenario, which is reduced to 1,424 million € by rising water prices 0.12 €/m^3, and to 1,306 million € by rising water prices 0.18 €/m^3. Banning groundwater overdraft reduces quasi-rent to 1,303 million €. Under the combined alternative, quasi-rent is 1,628 million € which is larger than quasi-rent under any other demand measure. The Ebro transfer project maintains current quasi-rent of farmers, but needs 301 million € in subsidies to keep the low water prices that farmers pay now.

A sharp reduction in water demand is achieved by raising irrigation water prices in the range 0.12-0.18 €/m^3. The current 2,550 hm^3 of water demand for irrigation falls by 500-600 hm^3, but the costs to farmers in quasi-rent losses are also quite high in the range 300-400 million €. Prohibition of groundwater overdraft is the worst solution because the fall in water demand is only 400 hm^3, considerably below the reduction achieved rising prices, whereas costs to farmers are higher than under the water pricing alternatives. The combined alternative of banning overdraft, water markets and desalination, reduces irrigation demand by almost 400 hm^3 at a much lower cost, less than 100 million € in terms of farmers' quasi-rent. The combined alternative also secures an end to aquifer overdraft.

Some caveats should be emphasized about the difficulties of implementing demand management measures. Decades of water resources mismanagement in the southeastern basins of the Iberian Peninsula, have created pervasive pressures on water resources and a severe degradation problem.

Table 3. Water demand scenarios in southeastern basins and Ebro project allocation (hm^3).

	Júcar basin	*Segura basin*	*South basin*	*Total Levante*
Current Water Demand	1,450	863	232	2,545
Water Demand Reduction for Agricultural Use…				
...by banning groundwater overdraft	139	213	70	422
...by increasing 0.12 €/m^3 water prices	313	142	54	509
...by increasing 0.18 €/m^3 water prices	350	181	74	605
...by combined alternative (banning overdraft, water markets, desalination)	139	213	10	362
Ebro Project Allocation				
All uses	300	420	100	820
agricultural and environmental use	141	362	58	561
urban and industrial use	159	58	42	259
Effective Demand of Water for Agricultural Use…				
...at prices for transferred water (0.20 to 1.05 €/m^3)	761	294	132	1.187

The measure of banning aquifer overdraft is very difficult to achieve since there currently is no effective control on the number of wells or the volume of abstractions. Water pricing measures are also difficult to implement because farmers will oppose price increases and because basin authorities have no control on costs faced by individual farmers pumping from aquifers.

Creation of water markets is also a difficult task. Although there are informal water transactions, the possibility of formal water markets introduced by the reform of the water law has not spurred any significant trades in the last five years. The reason is that farmers distrust formal water markets.

Augmenting water supply by desalination with public financing is much more straightforward, but the problem is the effective irrigation demand if water is not subsidized and farmers face the high desalination prices. The potential of desalination is given by the effective demand for desalinated seawater, that reaches 387 hm^3 in coastal counties from Safor to Campo Dalías, at the 0.52 €/m^3 cost of desalinated seawater.

The problem for this effective demand to materialize is that farmers are extracting water from aquifers at pumping costs around 0.09-0.18 cents €/m^3. Since pumping costs are considerably below desalination, farmers will not buy desalinated water. The public investment is desalination plants are only reasonable under a strict enforcement by the water authority of aquifer overdraft prohibition, that would force farmers to buy desalinated water.

This last point summarizes the problem faced by the new AGUA project, that is supposed to substitute for the Ebro transfer. As indicated above, there is an hypothetical effective demand in these counties amounting to 387 hm^3, but implementation of the AGUA project requires the strict enforcement of aquifer overdraft prohibition, and this is a daunting challenge for the water authority.

Table 4. Quasi-rent losses under alternative scenarios and subsidies (million € per year).

	Júcar basin	*Segura basin*	*South basin*	*Total Levante*
Current Quasi-rent	586	536	589	1,711
Quasi-rent Losses to Farmers...				
... by banning groundwater overdraft	46	101	261	408
... by increasing 0.12 €/m^3 water prices	166	94	27	287
... by increasing 0.18 €/m^3 water prices	232	136	37	405
... by combined alternative (banning overdraft, water markets, desalination)	39	49	-5	83
Subsidies Needed by the Ebro Project…				
… to cover the gap between costs of transferred water (0.20 to 1.05 €/m^3) and present low water prices	54	187	60	301

4 Nonpoint pollution control instruments in agriculture

Agricultural nonpoint pollution is a complex issue requiring information on pollution emissions at the source, transport and fate of pollutants, ambient pollution loads and their damage costs. Moreover, the physical, economic and social dimensions of the problem are such that they require multi-disciplinary and multi-scale approaches. In the case of Spain, nonpoint pollution is addressed at present by the domestic National Hydrological Plan and National Irrigation Plan, and by the European Union's Common Agricultural Policy, Water Framework Directive and Nitrates Directive. The consistency of these policies to abate pollution is far from evident and difficult to assess.[1] An example of their inconsistency is the nonpoint pollution impact of higher water prices advocated by the Water Directive, which is discussed below.

The results presented here are limited and do not cover the whole range of factors affecting agricultural nonpoint pollution. The CAP reform of 2003 and further trade liberalization by the EU will change land use patterns in irrigated agriculture at the extensive and intensive margins. Both abandonment and a more intensive use of irrigation are expected, depending basically on the availability of human and capital resources in agricultural regions: more intensive irrigated agriculture is likely in Mediterranean coastal areas of Spain, while inland collective irrigation areas are expected to stagnate. Another limitation relates to the range of pollution instruments considered. This is the case of wetland creation or recovery, which is an efficient instrument for large nitrogen abatement reductions [13]. Among the different nonpoint pollution issues, the information presented here tackles the question of the appropriate base instrument for nitrogen pollution abatement, which requires information on the underlying biophysical processes. This is a key question for the design of policy measures, and in particular for the design of the Program of Measures [11] of the Water Directive.

[1] Martínez and Albiac (2004) discuss the consistency of these polices [11].

Table 5. Results of key variables under the baseline scenario by crop.

	Production (Tons/ha)	Water use (m^3/ha)	Nitrogen use (kg/ha)	Nitrogen leaching (kg/ha)	Quasi-rent (€/ha)
Corn	14.1	6,220	325	140	1,180
Barley	6.0	2,200	180	29	375
Wheat	6.6	3,500	140	32	550
Sunflower	2.9	3,100	70	20	470
Alfalfa	17.3	7,800	70	15	740
Rice	5.6	12,000	170	57	797

The acute scarcity of information in Mediterranean agriculture, on the biophysical processes involved in pollution and the associated damage costs means that measures cannot be reliably assessed.

The effects of selected abatement measures have been examined through a dynamic model, which includes six crops and one representative soil, in the Flumen-Monegros irrigation district located in the Ebro basin of Spain (Table 5). Ranking the nitrogen control instruments by their cost efficiency contributes to the information needed in the policy decision process. The results obtained agree with previous literature, and indicate that a fertilizer standard is the more efficient second best measure to control nitrogen pollution (Table 6).

An increase in water prices only slightly reduces nitrogen discharges at very high costs to farmers and society. A tax on nitrogen fertilization results in more significant pollution reduction at much lower costs. A standard on nitrogen application curbs emissions by more than half, with a very moderate impact on quasi-rent and gains in welfare. The introduction of subsidies linked to the standard could be a good second best instrument to achieve nitrogen pollution control.

The finding that higher water prices are very inefficient to abate emissions, questions the reliance of the European Water Framework Directive on water pricing as a pollution instrument to reach the “good status” target for all waters. The implication is that other instruments included in the Directive, such as ambient quality standards and emissions limits, need to be applied in order to curb pollution.

The results contribute with further evidence to the discussion on the choice of the appropriate instrument base for nitrogen control. Horan and Shortle [9], using the empirical results by Helfand and House [8] and Larson *et al.* [10], state that instruments based on irrigation water are more cost efficient than instruments based on nitrogen fertilization.

Table 6. Results of alternative policy measures in the district.

		Welfare (10^6 €)	Quasi-rent (10^6 €)	Water (hm^3)	Nitrogen (Tons)	Percolation (hm^3)	Nitrogen leaching (Tons)
Base Scenario		22.3	24.1	190.7	4,525	66.1	1,459
Water price	0.06 €/m^3	21.2	18.8	86.4	4,367	43.3	1,381
	0.09 €/m^3	19.6	12.6	109.1	4,039	20.2	1,346
Nitrogen price	0.90 €/kg	22.4	22.6	200.6	4,265	45.3	1,222
	1.20 €/kg	22.7	21.5	186.6	3,976	56.2	990
Nitrogen standard		23.7	23.8	98.1	4,134	14.1	634
Emission tax		23.9	23.8	185.4	3,596	43.4	697

The reason given is that irrigation water is more highly correlated with nitrate leaching, implying that the appropriate instrument base is not the nutrient responsible for pollution but rather the input most highly correlated with pollution. This interpretation appears inaccurate, because the dynamics of nitrogen in the soil are ignored. Neglect of the dynamic aspects of nonpoint pollution may have serious consequences for the design of policy measures.

An important question for the choice of the correct pollution control instrument, is the implementation costs of the instruments. Measures that seem suitable may be associated with implementation difficulties relating to their political acceptability or transaction costs, and policy makers should evaluate the trade-off between cost-efficiency and simplicity of implementation.

5 Conclusions

Mediterranean countries have a large irrigation demand for water resources, which creates significant water quality problems compounded by water scarcity. The strong policy debate that has been taken place in Spain to overcome water scarcity and resource degradation, highlights the difficulties to attain a sustainable water resources management, because of the conflicting interests of diverse stakeholders: regions, economic sectors and political and environmental groups.

Two distinct general policy approaches to deal with Mediterranean water quantity and quality problems, are the traditional approach of expanding water supply and new emerging water management initiatives. Examples of the traditional approach are interbasin transfers, seawater desalination, and to some degree subsidies to upgrade irrigation systems. New emerging initiatives rely on measures such water pricing, revision of water rights, abstraction limits on surface and subsurface waters, development of regulated water markets, and water resources reuse and regeneration.

The effects of these measures on water quality is difficult to ascertain. It seems that expanding water supply may have negative effects on nonpoint agricultural pollution, because it favors the expansion of high profitable irrigation in Mediterranean coastal agriculture, that can pay for this additional water supply.

Water pricing does not seem to be a good measure to improve water quality for two reasons: i) it does not reduce water demand in coastal areas with high profitable crops and severe pollution problems, and ii) in inland areas with low profit crops, it is not a good nonpoint pollution instrument to abate pollution. The implication is that other water management initiatives are needed to abate pollution, such as ambient quality standards and pollution emission limits at the source.

Several issues have been examined by presenting empirical evidence from Spain on alternative policy options and measures. The measures examined cover two cases: the evaluation of alternatives to solve water scarcity in southeastern Spanish basins, and ranking agricultural pollution control instruments by their cost efficiency.

The first case is the recent Ebro transfer project and the new AGUA project designed to substitute for this transfer. Both projects are very illustrative examples that highlight the failure of approaches based on expanding water supply. Results from analyzing the Ebro transfer, show that a combined alternative of banning aquifer overdraft, water trading and a small volume of desalination, is by far a better alternative than building the Ebro transfer.

Augmenting water supply by desalination with public financing is politically appealing for the new Spanish government after canceling the Ebro transfer, and its AGUA project seems a straightforward measure. But the problem with the AGUA project is finding the effective irrigation demand if water is not subsidized, because farmers will face high desalination costs. Farmers are extracting water from aquifers at pumping costs considerably below desalination, and they will avoid buying desalinated water. Only a strict enforcement by the water authority of aquifer overdraft prohibition, would force farmers to buy desalinated water. This is a daunting challenge for the water authority, and the risk of the AGUA project is that public funds are invested in desalination plants, but then the irrigation demand does not materialize.

The second case examined, compares several measures to abate agricultural nonpoint pollution. Selecting the right policy measure requires knowledge on the underlying biophysical processes, and lack of information on these processes involved in pollution and the associated damage costs to fluvial ecosystems means that measures can not be reliably assessed.

Ranking nitrogen control instruments by their cost efficiency shows that a fertilizer standard is a good abatement measure, in accordance with previous literature. In contrast, rising water prices is very inefficient and this finding questions the reliance of the Water Framework Directive on water pricing as a pollution control instrument.

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SUSTAINABLE ALTERNATIVES OF WATER MANAGEMENT IN URBAN AREAS OF MEDITERRANEAN COASTAL CITIES: THE EXAMPLE OF BARCELONA METROPOLITAN REGION (BMR) (NE SPAIN)

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Here we studied water management strategies for the Barcelona Metropolitan Region (BMR, 4.5 million people) from the perspective of sustainability and the New Water Culture. These principles advocate that options to provide water supply be analyzed following five criteria: capacity, guaranty, monetary cost per unit of water obtained, water quality, and environmental impact. These criteria were examined for several water management strategies suitable for the BMR, which were chosen after interviews with experts and managers from the Catalan Water Agency. We conclude that up to 200 hm^3/year could be obtained by combining 6 measures that provide additional water for human consumption and 3 measures that improve the efficiency of water use. Consequently, the Ebro inter-basin transfer proposed in the former Spanish National Hydrological Plan would be unnecessary.

1 Introduction

In Spain, as in many other countries, especially developing ones, current water management is based mainly on the "hydraulic paradigm" [1]. From this standpoint, water is a resource that should be available to cover human needs and should not be subjected to restrictions. Therefore, water may be abstracted, transported and used like any other resource, by means of hydraulic mechanisms as a main management strategy to meet water demand. Until recently, the economic development of Spain has been given more priority than the effects on aquatic ecosystems caused by the engineering works required for this development. Following the hydraulic model, and during the 20th century, technology and public funding allowed the construction of millions of hectares of irrigation fields, thousands of kilometres of canals, hundreds of reservoirs and several basin diversions. As a result, aquatic ecosystems have suffered deep environmental impact. The flow of many rivers has decreased and in some cases completely dried up. The input of millions of tons of domestic and industrial sewage, together with the diffuse pollution from irrigation fields, have had a dramatic effect on aquatic ecosystems, as summarized in the Spanish Government White Paper [2]. Many of the point-pollution inputs have improved water quality in the last 15 years because of the construction of sewage plants; however, the ecological status of aquatic environments in Spain remains poor, with more than 50% of rivers polluted and more than 50% of the reservoirs eutrophic [2, 3].

In spite of this situation, a National Hydrological Plan based on the hydraulic paradigm was approved by the Spanish government in June 2001. This plan included the building of more than 100 new reservoirs, the creation of more than 1 million hectares additional new irrigation fields and a 25% increase in water use by industry and for domestic purposes. The increase in water use is greater along the Mediterranean coast, precisely the area in which resources are scarce and the ecosystems in worse condition. To cover the increasing water requirements in this area, the plan proposes to transfer water from the lower part of the Ebro river (close to the mouth) to the south (900 hm^3/year) and to the north (190 hm^3/year), mostly for meeting the needs of the Barcelona Metropolitan Region (BMR). The transfer to the south is mainly for irrigation purposes, while to the north it is generally for urban and industrial use. The effects of the plan on the ecosystems of the Ebro and its environmental, social and economic impact will be enormous and have been summarized elsewhere [4].

The approval of the plan in 2001 generated great social and environmental contestation in the areas that were to be most negatively affected by the transfer (the Ebro basin, particularly the lower part). In response, alternatives to this plan, following sustainable development strategies, have been proposed. The general public and numerous scientists have joined efforts to establish a platform for a “New Water Culture” (NWC). Comprising people from a range of scientific disciplines (biologists, geologists, chemists, economists, geographers, etc.) and social movements (environmental NGOs, politicians, etc.), this movement has staged mass protests against the plan and organized alternative scientific and social meetings to address a new strategy of water management in Spain. The movement has established the Foundation for a New Water Culture (FNWC), an organization that seeks to promote a new model of water management (the NWC) as an alternative to the current system, which is based mainly on water balances (the hydraulic paradigm).

The NWC demands respect for the structure and function of the ecosystems from where water is used to support human activities (domestic, agricultural or industrial). The social dimension of the NWC is one of its major attributes and the interdisciplinary of the members of the FNWC is a guarantee of the multi-factorial comprehension of water issues. The development of this new model of water management has been summarized in [5]. Recently, the Foundation adopted the “European Declaration of the New Water Culture”, signed by more than 100 scientists, which aims to extend this model to the rest of Europe (see www.unizar.es/fnca).

Beyond a mere list of technical measures, the FNWC implies a radical change in social perception of water and current management practices. This organization endeavours to make society at large aware of the water it uses every day and consider its origin and the environmental impact of its use. The efficient management of such a valuable resource is essential for Mediterranean countries as in the future they will be affected by increases in water consumption and decreases in resource availability because of climatic changes.

In March 2004, general elections were held in Spain and the government changed hands. The newly elected president fulfilled one of his manifesto promises and halted the Ebro inter-basin transfer. In the absence of this transfer, the BMR must develop new water management practices to cover its requirements.

Here we define the future water management in Catalonia in a scenario without further water transfers and under the principles of the NWC. For this reason, the Regional Government set up a task-group in water administration, with the objective to produce a strategic document to identify sustainable alternatives for water management for the BMR. This group was coordinated by members of the FNWC and two managers from the Catalonia Water Agency (CWA). Here we summarize the results of the document drawn up by this group in 2004 and its present state of implementation.

2 Study area

Catalonia is a relatively small region in NE Spain. A large part of its territory lies along the coast in a typical Mediterranean climate zone. More than 5.5 million people live in a coastal strip occupying less than half of its territory; a common feature of many Mediterranean areas. Several coastal, relatively short rivers drain this territory. These rivers have been diverted, dammed and overexploited for many years (following the hydraulic model) to provide water for urban, agricultural, tourist and industrial uses. Consequently, aquatic ecosystems in the region, from rivers to wetlands, are plagued by environmental problems caused by reduced flows and increased pollution. Water abstraction and pollution are present from the upstream areas of river catchments to the mouths of their Mediterranean rivers and streams. Until now, water management practices have been limited to providing water for domestic use and to abating pollution using end-pipe measures, such as sewage plants. Environmental flows have not been implemented in the area and water conservation measures and pollution prevention activities are scarce.

3 Methods

3.1. *Principles of the analysis*

The analysis of the strategic document on sustainable water management for the BMR was made following the guidelines of the Water Framework Directive (WFD) and the NWC. The WFD aims to maintain and restore aquatic ecosystems of the European Union and achieve good ecological status of European waters by 2015. The main objective of the NWC is to balance the needs of humans with those of the environment, thereby maintaining the structure and function of aquatic ecosystems, objectives that are similar to those of the Directive.

According to the WFD, the 4 principles on which the new model of water management in Catalonia should be based are: sustainability, subsidiarity, efficiency and public participation. Sustainability implies no further deterioration and greater protection of aquatic ecosystems. The application of subsidiarity means that water management decisions should be taken locally, as near as possible to where water is used or degraded. According to the efficiency principle, the most beneficial combination of measures (economic and ecological) should be applied. Finally, public participation assures acceptance of the measures proposed.

The measures adopted to guarantee water supply and good ecological status of aquatic environments must be evaluated following several criteria, including capacity (quantitative supply potential); guaranty (availability of water); water quality for domestic use; economical cost (to use or save water); environmental impact (local or global); and social and political issues (which may impede the desired result). Here we evaluate these criteria both qualitatively, for all the measures proposed, and quantitatively, for those with relevant information available in the records of the CWA.

3.2. *Data collection*

The main objective of the strategic document has been to identify measures that may provide (or save) enough water to guarantee adequate quality of water supply for the BMR, without causing more environmental concern on the ecological status of the rivers in the region, the Llobregat and Besòs, which flow though this area and cover 2/3 of water requirements (surface and groundwater resources). The same is applicable to other rivers which supply the BMR, because 1/3 of the water used in the area is from another watershed located 100 Km to the north of the city of Barcelona, the river Ter. Without this water transfer the BMR would face severe water shortages.

The CWA has extensive information on water consumption, water use and savings, water quality, among others. As our analysis was solely to identify the basis for future management and the deadline was short, no new studies were proposed and the strategic document was produced from existing information. Over two months, we held meetings with managers from several areas of the CWA at its headquarters and information was collected and summarized by an executive committee in which the two authors of this study were the coordinators. The information was compiled, and a series of discussion articles were produced. The strategic document was later discussed with the members of the CWA and the final document was made public for general discussion in a series of meetings (The complete document in Catalan is available at www.gencat.net/aca).

The main conclusions of the strategic document were adopted by the Regional Government (*Generalitat de Catalunya*) as a basis for its National Water Plan, to be implemented in 2006-09 when planning of the WFD is scheduled to occur. Issues concerning the ecological status of waters in Catalonia and the measures required to restore them to a healthy status are currently being addressed by the CWA. In the meantime, this agency will focus on the development of the managerial strategies proposed in the document. These measures should guarantee the BMR water resources of adequate quality during the coming years.

4 Results

Several measures were discussed by the task group at the CWA. The list of measures included two ways of increasing water availability: those that increase resources, and those directed to saving water and therefore to decreasing water abstraction. In both cases, the first step in the analysis was to identify all the measures that result in greater water availability.

To increase water availability, the measures selected were as follows: improved management of reservoirs and weirs; building new reservoirs; building desalination plants; increasing water quality though better sewage treatment; water reuse; changes in water use in agriculture; use of rain water; improved management of aquifers; and water transfers from the Ebro or Rhone rivers. Measures considered useful to save water included: domestic savings using more efficient taps and toilet flushing apparatus; industrial savings; water conservation in agriculture; water markets; and more efficient use of water in buildings belonging to public administration.

The qualitative analysis of these measures is presented in Table 1, in function of the six criteria presented in the methods section. Given that the building of new reservoirs and the realization of new transfers imply a very large environmental, economic and social impact, these measures were discarded from further discussion.

Using the information collected by the CWA task-group, we next evaluated the capacity of the remaining measures to obtain or to save water. Our preliminary results are shown in Table 2, which offers a perspective of the water that can be obtained by each measure in the short- (4-6 years) and long-term (more than 6 year from now). The true values for several of the measures are now being studied in specific plans. Many of the measures proposed were not previously considered by this agency (because the hydraulic paradigm was the rule) and therefore few data are available for these (for example the possibility of saving water in domestic use, official buildings or the collection of rain water).

The criteria that may help authorities to select the best measures in Table 2, which were evaluated quantitatively, are shown in Table 3. We obtained enough information for only 4 of the measures. It was not possible to obtain data to apply and calculate the criteria for agricultural uses. However, agricultural demand for water in the BMR is not large and therefore potential savings in this field are not as great as in other parts of Spain. According to this table, the best options are the use of polluted groundwater, by applying advanced water treatment, and the reuse of treated wastewater. Furthermore, the abatement of pollution is crucial to increase water quality both for supply and for environmental reasons.

Table 1. Qualitative analysis of the measures selected to increase water availability for the Barcelona Metropolitan Region. Each measure is classified into 5 ranks for the six criteria: VH = Very high H = high, M = Medium, L = Low, VL = Very low.

Measure	Capacity	Guaranty	Quality	E. Cost	Env. Impact	Social& Political
Managing reservoirs	M	H	M	H	H	M
New reservoirs	M	M	M	VH	VH	VH
Desalination	H	VH	VH	H	M	M
Better sewage treatment	L	H	M	H	L	L
Water reuse	H	H	M	H	L	L
Water markets (Agric.)	M	M	M	M	L	M
Use of rain water	L	L	H	M	L	M
Aquifer efficiency	H	H	M	H	L	L
New water transfers	H	M	L	VH	VH	VH
Domestic savings	L	M	M	H	L	L
Industry efficiency	M	M	M	M	L	L
Agriculture efficiency	M	M	M	M	M	M
Water markets	M	M	M	M	M	M
Efficiency in public administration buildings	L	L	M	M	L	L
Water pricing	L	M	M	H	L	H

Table 2. Summary of the potential increase in water supply and water savings obtained using the measures identified as alternatives to water transfer in Catalonia (data in hm^3/year)

Measure	4-6 years	> 6 years
Management of reservoirs	20	8?
Desalination	10+30+30=70	30
Better sewage treatment	8	
Groundwater management	50	30
Water reuse	13	12
Water from agriculture	30	
Domestic efficiency	10-17	20-32
Water pricing	No data	
Water network	4	
Efficiency in industry	15	
TOTAL AMOUNT OF WATER	Up to 228	Up to 112

The study was performed during May and June 2004. Later on, and in response to a request by the Spanish Government, the Regional Government of Catalonia produced a document outlining the investments required in this region for securing water supply and as an alternative to the Ebro inter-basin transfer. The measures considered in the strategic plan (Tables 1 and 2) were taken into consideration only in part for the investment demands (see Table 4). We classified the future investments into three groups. 1: Measures that will increase resource availability (all are considered in the strategic document, see Table 2). 2: Measures to increase water quality (most are also included in Table 2, although no new resource is provided). 3: Infrastructural measures, which, in some cases, may increase water availability through efficiency.

Table 3. Evaluation criteria for alternative measures to increase water availability in the Barcelona Metropolitan Region.

Criteria/Measure	Improving water quality	Water from aquifers	Water reuse	Desalination
Guaranty	Indirect though quality	100% Up to 40 hm^3	100%	100%
Water quality	Large increase	Very high using reverse osmosis	Increase	Increase
Economic cost	Low	0.10-0.25 €/ m^3 including water treatment	0.15-0.20 €/ m^3	0.4-0.5 €/ m^3
Use of Energy	Not significant	0.5-1.5 kWh / m^3	1-1.5 kWh / m^3	3.5 kWh / m^3
Environmental impact	Positive for the whole ecosystem	No impact	Positive	Moderate. No affect on Posidonia beds

The table shows that almost one third of the investment will be for the conservation and development of new infrastructure to maintain the present water supply and to increase the interconnectivity of networks. Another third will be used to increase the quality of present resources without involving further water production. Finally, a third will be used for several of the measures identified in Table 2 in order to increase water availability, partly through the production of new resources (desalination) or the improved use of present resources, especially water from aquifers or by increasing the efficiency of the system. These investments will lead to a total of 140 hm^3/year of additional water. This amount is similar to that reported in Table 2 for the same measures. Therefore, the estimations included in the strategic document are consistent with the future investments in water management planned by the Regional Government. However, many measures in Table 2 are not included in investment previsions, and therefore further opportunities to save and increase water resources remain.

5 Discussion

Water management in Mediterranean countries relies mainly on the building of large reservoirs and the long-distance transfer of this water to cities located close to the coast, or to irrigation fields. Although agriculture accounts for the most consumption of water in the Mediterranean area, cities, such as Barcelona, use great amounts of water from reservoirs. In a future of increasing demand and with the uncertainties of climatic change, although the construction of more reservoirs is included in the Spanish National Hydrological Plan, this measure will not solve the environmental and water supply problems faced by the Mediterranean area of Spain.

Table 4. Future investments of the Regional Government of Catalonia (*Generalitat de Catalunya*) to increase water availability and to ameliorate water quality.

	Capacity hm^3/year	Investment Cost (10^6€)	Unit cost 10^6€/hm^3
Measures that will increase resource availability			
Efficiency in the use of present resources	23.8	97	1.04
Improvements in the present systems of water production	20	46	2.3
Water reuse	11	91	8.27
Aquifer improvements (quantitative and qualitative)	18	22	1.22
Desalination	70	201	2.87
Measures to increase water quality			
Sewage plants (new or improvements of current facilities)		168	
Abatement of salt inputs to the Llobregat		90	
River restoration, including riparian areas		131	
Infrastructure to maintain, interconnect and renew the present water supply system		314	
TOTAL INCREASE IN WATER SUPPLY	140		

Therefore alternative measures to save and to increase the availability of water for present and future requirements should be developed for Mediterranean countries. These measures should be based on an integrated management strategy which focuses on sustainability, as proposed for other Mediterranean streams [6]. Measures with low or null environmental impact should be implemented rather than more structural works. The use of non-conventional measures (water reuse, water from polluted aquifers, desalination, etc.) is a central point of this alternative management. The main objective is to guarantee water for domestic use while maintaining a good ecological status of freshwater ecosystems, thereby complying with the regulations of the WFD.

Our study shows that more sustainable water management, based on the use of available resources, together with some desalination and an increase in the efficiency of present use, may meet the current water requirements of the area. A more detailed analysis is currently being performed on the implementation of this plan, particularly its economic feasibility and how it compares with inter-basin transfers. Indeed, desalination compares well with water transfers [7], and therefore alternatives to these transfers are, in most cases, less expensive.

In our proposal, the water obtained through reuse and aquifers should be considered as a strategic resource that will be crucial in the future, particularly in periods of drought [8]. Therefore, to alleviate the pressures on the present main providers (the rivers Ter and Llobregat), we recommend the building of a desalination plant in the area, which may cover almost 15% of the present demand. This plant would make a considerable contribution to increasing the ecological status of the river Llobregat (with high salt content because of mining) and would improve the quality of water for domestic use in Barcelona.

Until now, water management in the Mediterranean and in the BMR has followed the hydraulic paradigm and the management of water quantity (water resource management). In the future, integrated river basin management should be developed. With this strategy, the conservation of ecological functions can be combined with water resource development [9]. Furthermore, the management of water resources in the BMR should involve cooperation between the authorities and the citizens [10]. Our analysis is the first step to establishing a new water management strategy for the BMR following the NWC and the principles of sustainability.

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THE PROFESSIONAL AND INTELLECTUAL CHALLENGES OF SUSTAINABLE WATER MANAGEMENT

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Scholars and practitioners agree that water resources management is an interdisciplinary venture, requiring expertise from multiple perspectives. Traditional fields of expertise in water management have included chemistry, biology, engineering, and finance. In the 21st century, far broader disciplinary engagement is needed if global water supply challenges are to be met, including better integration of social sciences. This paper summarizes complex challenges facing today's water decision-makers and managers and then identifies the intellectual and professional requirements for meeting the challenges. The paper calls upon the water industry to help build the intellectual capacity needed to help them meet water challenges, while also identifying reforms in academic organization that will facilitate productive research. Examples of innovative water resources research efforts are provided.

1. Introduction

Society's greatest and most enduring conflicts arise when the internal logic of rival claims is indisputable. The subject matter of conflict can be far-reaching – claims on territory, on when human life begins, on interpretation of religious texts, on the implications of nationalism. Humans have a profound ability to commit themselves to their beliefs; thus conflicts can drag on from year to year, simmering and boiling, passing from one generation to the next. This may well be the fate of 21st-century conflicts over fresh water resources, but it is not a certainty. Academic, political, and moral leaders of society cannot create more water, but they have an opportunity to re-cast water issues in ways that build bridges of understanding and identify broadly-acceptable management approaches.

This paper argues that innovative, collaborative approaches to water-resources research are needed if society is to make good decisions regarding its fresh water resources. Many more perspectives on water issues are needed both inside and outside of academia. Within academia, water issues should be put squarely on the agendas of many, indeed most, disciplines. Outside of academia, water professionals should become more willing to engage with academia and the public. Members of the public should organize and prepare themselves to take active part in what promises to be a very long dialogue.

1.1. *The Confused Moral Landscape of Fresh Water Research*

When engaging water issues, there are at least two starting points: the hydrologic and the normative. The hydrologic starting point takes on the biogeophysical questions: for a given region, how much water is there; where is it; when is it available; what is its quality; what natural and human-caused features influence its availability and quality. The fields of ecology, hydrology, agronomy, and earth system sciences are contributing in this area. One example of a new research program linking these areas is the Pajaro Valley/Pajaro River, California, research program initiated by Andrew Fisher, a hydrogeologist collaborating with agro-ecologists, soil scientists, social scientists, and surface-water regulatory agencies to understand interconnections between river banks and groundwater resources, including flow and nutrient exchange (briefly introduced at http://www.steps.ucsc.edu/collabs.html).

The second starting point for fresh water research, the normative one, is concerned with how a given society construes what good water practices. The term "good" hinges on a broader vision of a just society. Both history and current-day experience show us that there are many such visions, and some of them have the potential to collide with each other and result in zero-sum competitions over resource use.

Consider the normative foundations and implications for action of the following two widely-recognized sets of facts about the global water situation. The first set concerns access to water for human use:

- (T)oday more than 2 billion people are affected by water shortages in over forty countries: 1.1 billion do not have sufficient drinking water and 2.4 billion have no provision for sanitation. […] Current predictions are that by 2050 at least one in four people is likely to live in countries affected by chronic or recurring shortages of freshwater (UNESCO-WWAP, 2003: 10).

The second set concerns water removal from natural systems:

- Globally, humanity now uses more than half of the runoff water that is fresh and reasonably accessible, with about 70% of this use in agriculture. To meet increasing demands for the limited supply of fresh water, humanity has extensively altered river systems through diversions and impoundments. In the United States only 2% of the rivers run unimpeded, and by the end of this century the flow of about two-thirds of all of Earth's rivers will be regulated. […] Major rivers, including the Colorado, the Nile, and the Ganges, are used so extensively that little water reaches the sea. Massive inland water bodies, including the Aral Sea and Lake Chad, have been greatly reduced in extent by water diversions for agriculture [16].

Both of these quotes paint pictures of deep concern with the management of the world's water resources. Each has its own conception of what constitutes good management of water. The UNESCO quote frames the long-term challenge of global water management in terms of improving access to water and sanitation services. The Vitousek *et al.* in [16] quote frames the future in terms of retaining what is left of natural flow regimes. Each vision for the future is built upon solid normative justifications. For the UNESCO quote, the sanctity and primacy of human life, the moral imperative to alleviate poverty, and the equity-based need to provide comparable opportunities for health and longevity to all peoples drive to the conclusion that natural sources of water should be utilized for purposes of human water consumption and sanitation needs. For Vitousek *et al.* [16], the concern is with the maintenance of intact ecosystems both for their inherent value as well as for their long-term ability to provide human society with a variety of important services. The UNESCO approach is clearly anthropocentric (human-oriented) while the Vitousek *et al.* [16] approach combines anthropocentrism and biocentrism.

These two approaches provide different ways of framing what constitutes good management of water resources. While there is some overlap, they aim us toward different futures. We cannot achieve both visions of the future. Good choices of infrastructure projects and good management practices for one vision would be problematic in the other. Solving the problem identified by UNICEF – making water more accessible to over one billion people – would create its own environmental catastrophe. Ready access increases consumption dramatically as the difficulties of individually acquiring and transporting water are removed. If daily per-capita use increased 75 liters as a result of universal access, the resulting new use of water would be 27 trillion liters per year, a volume of water carried only by the world's largest rivers. This additional draw, along with the required engineering interventions in the natural systems, would likely result in massive extinctions of riverine and wetland-based species. This general absence of a shared normative vision of the future management and allocation of water resources is contributing to the slow progress achieved thus far on global goals for improved water management. The gridlock over whether nations and multilateral agencies should support dams and other large-scale infrastructure projects is one example.

1.2. *The Role of Academia in Fresh Water Research*

The traditional disciplines of fresh water research – chemistry, biology, engineering, and finance – are as important as ever. But fresh water issues have exploded beyond the boundaries of these research areas, encompassing nearly all the natural, physical, and social science disciplines, as well as research in professional schools. Table 1 presents a partial list of disciplines and water-related topics that would benefit from scrutiny by scholars trained in those disciplines. Although Table 1 is many lines long, readers will most likely identify numerous other topics of importance at least equal to those listed. This underlines the point that water issues increasingly demand the attention of the scholarly community.

Table 1 also reveals another aspect of water research – it requires either individual training in multiple disciplines or collaborative research, or both. Crucial issues related to water management and allocation combine complexities, scale, and scope often too large for one scholar to handle. Engineering training has traditionally been interdisciplinary and problem-oriented. This style of training is needed across the social sciences so that young scholars emerge with the tools needed to understand the many faces of water issues: biogeophysical, engineering, social, and normative (see, e.g., [10]).

Table 1. Academic Disciplines involved in Urban Water Supply (Note: many of the topics are interdisciplinary but fundamentally require insights and tools from the discipline under which they are listed).

Discipline	Topics
Ethical issues (Philosophy)	
	Intergenerational distribution of benefits
	Equitable reception of service
	Trade-offs between mutually-exclusive benefits
Legal Issues	
	Extent of ownership/use rights
	Ability of cities to secure new supplies beyond urban borders
	Transboundary water flows
Economic Issues	
	Finance
	Institutional efficiency
	Engineering efficiency
	Comparing alternative supplies/uses
	Prioritizing sources, uses, and sinks
Psychological Issues	
	Communications strategy (individual use/health; public choice)
	Human reactions to water reuse; history of water; naturalness of water; water contamination
Political Issues	
	Political boundaries and water rights
	Land-use planning
	Decision-making processes
	Links between water rights and land rights
Anthropological Issues	
	Links between water-use practices and culture
Sociological Issues	
	Environmental Justice/Equity
	Gender differences in use/access
Ecological Issues	
	Watershed management
	Wastewater/brine disposal (terrestrial, river, marine)
	Aquifer and surface-water management
	Disposal/use of biosolids
	Climate change and water availability/timing
Public Health Issues	
	Drought planning
	Water quality monitoring
	Public advisory systems
	Wastewater and biosolids management
Engineering Issues (chemical, biological, structural, civil, environmental)	
	System coverage
	System reliability
	Treatment technologies
	Monitoring systems
	Disposal systems
Chemistry/biology issues	
	Treatment technologies and protocols
	Monitoring technologies and protocols
Computer Science issues	
	Remote sensing of flow, quality, and other parameters

2. An Example: the Challenge of Urban Water Supply

The practices of water planning, management, and regulation are growing in complexity. There is better understanding of the role that water plays in natural systems, and the value to human society of keeping the water in natural systems. There are new methods of modeling the flow of underground water so that hydrologic links between groundwater and surface water are better understood. Rapid transformations of land (especially agricultural-urban transformations) are changing the location and types of use of water, while the combination of economic growth and human demographic growth is putting additional demand on water supply. Often, new understanding and trends in water supply cause historical legal boundaries to become hindrances to good management, rather than aids. Overlying these challenges are poorly-understood but serious issues surrounding invasions of non-native species that can alter a region's water balance or change a region's fire regime, and global warming that could change precipitation, runoff, and water demand patterns.

Global society is responding to these new trends in many ways. New water treatment technologies are available, lowering costs and making additional water resources available from reclamation and desalination. New approaches to financing water projects are being tested. And new approaches to public participation and the governance of water at local, regional, and broader scales are being considered. At the same time, the normative question of what constitutes good water management often has more than one answer, with mutually-exclusive policy prescriptions emerging from each answer.

The following example brings into focus the complexity of one aspect of water-management challenges, urban water management, and the many disciplines needed to make headway. In many parts of the world, cities are experimenting with the institutional structure of urban water supply and treatment. The popular discussion is broadly cast as "government ownership vs. private ownership" of water supply and services. Neither of these poles exists in reality. Below, I provide a framework intended to help sort out what is unique about urban water supply and what options for institutional governance are available. The framework integrates property rights theory, new institutional economics, civil engineering, and biogeochemistry into a watershed perspective on urban water supply. I draw on a case study from South America (Lima, Peru) to illustrate the vast problems faced by many of the world's cities with respect to water supply in the 21st century.

2.1. *The Misleading Polarity of "Public vs. Private"*

Although the popular debate and some scholarly literature remain caught in the *public vs. private control of water* controversy, researchers over the last half-decade have developed more nuanced, though no less controversial perspectives. There are many examples. In Australia, the term *corporatization* has come to mean a highly-regulated, thoroughly-reformed water sector that has a "commercial orientation" [11]. While Martin [11] finds promise for this model to deliver needed reforms to Australia's rural water industry, Smith [13] is skeptical that corporatization can integrate private-sector elements with the social-equity orientation that is crucial to managing urban water systems. Similarly, Rodriquez [12], notes that the focus should be on financing of water systems, not on who owns them. Consistent with Martin [11], he calls for public-private partnerships intended to get the needed elements from each approach: cost control, access to capital, and incentives for good performance from the private sector, and governance decisions and regulation in the public interest with public oversight. And Braadbaart [4] points out that privatization cannot deliver on its promise of improved economic efficiency in the provision of urban water in the absence of substantial reform of public regulatory oversight, underlining the co-determined public/private nature of outcomes in the water sector. It is difficult to identify what the tipping point is in the mix of public and private ownership and governance that switches a system from being “public” to being “private”.

Bakker [1] distinguishes between privatization (involving private firms in financing, management, and other aspects of water supply and treatment) and commercialization (invoking market mechanisms as a means of allocation). Privatization and commercialization are both governance choices, but are different in their scope and implication. This distinction overlays neatly and helps sort out on-going confusion between privatization as it affects the governance and operation of urban water systems and privatization as the concentration of rights to water to enable their transfer using market mechanisms (e.g., [3, 8, 14]). This example focuses on the former: the governance and operation of urban water systems.

Although the differences between industrialized and developing cities in terms of challenges facing their water systems are immense almost to the point of non-comparability, it is possible to find some common framing of the challenges and how one might approach them. One such issue can be characterized as *centralization vs. decentralization* of supply. Centralized systems include large-scale treatment facilities, integrated piping systems, and single agencies that handle all or nearly all the steps in the supply of water and treatment of wastewater. Decentralized systems are characterized by multiple, competing suppliers, different kinds of supply services, point-of-use treatment, and a partial- or full- de-coupling of sanitation services from water supply-services. Wilderer [18] provides an overview of potential benefits of decentralized systems in providing water and sanitation services in developing nations, noting that advanced technology could improve the performance and efficiency of such systems. In most parts of the world, hybrid centralized/decentralized systems exist. In the United States, this takes the form of bottled water bought in stores or delivered to homes and businesses; point of use water-treatment systems, and septic systems. In developing nations, this often takes the form of water trucks delivering water to households and community latrines.

2.2. *Characterizing Urban Water Supply*

Sorting out the appropriate mix of public and private participation in urban water supply is complex and, as Bakker [2] points out, dynamic. It is part of the larger challenge that encompasses the governance and operation of urban water and hygiene systems. The provision of urban water and sanitation services and wastewater treatment are multi-step processes involving interfaces with and utilization of natural systems, and extensive connections – physical, economic, political, emergency planning and response, and other – with communities served, as well as with surrounding watersheds and broader regulatory domains. Table 2 presents the physical stages of urban water use, each of which is subject to the same array of broader questions of governance and use.

Table 2. The Physical Phases of Urban Water Supply.

A. Withdrawal from Natural Systems and Transportation to Treatment Plants • Withdrawal from surface or groundwater systems • Could involve movement of water vast distances
B. Treatment • Prior to beneficial use
C. Delivery to end-users • Involves piping to residences, businesses, and government facilities
D. End Use • Residential, industrial, commercial, governmental
E. Collection • Capture and re-concentration of waste flows and delivery to wastewater treatment facility
F. Treatment • Typically capital-intensive, highly-technical facilities
G. Disposal • Reclamation and reuse of urban wastewater are growing trends • Disposal of byproducts (biosolids) also required

Heller *et al.* in [9], discussing information technology needs of water utilities, describe centralized urban water suppliers as “integrated businesses.” The public-private polarity can be better characterized as a three-dimensional grid encompassing individual steps in the provision of these services, who operates them, and how they are governed. For example, in terms of water supply, processes involved begin with drawing water from surface and/or groundwater systems and delivering it to treatment plants. Operations include building, maintaining, and operating the physical infrastructure of reservoirs, dams, wells, pumps, and pipelines. Governance includes water rights, environmental protection regulations, acquisition of rights of way, and maintenance scheduling and management. This first step clearly involves a combination of public and private action since even a fully-public utility regularly purchases specialized engineering products and services from private contractors. Even environmental protection activities can have private-sector connections when private firms undertake restoration activities as contractors to government agencies.

Likewise, the treatment phase prior to beneficial use is subject to extensive governance, ranging from cost control, long-term planning, supply/demand balancing, water quality monitoring, plant maintenance and operations, disposal of byproducts from treatment, to labor rules and practices. Straight through to disposal of wastewater, every phase of water supply and sanitation services has ample opportunities for public and private participation and governance. In reality, the provision of these services is inescapably a mix of public and private ownership and oversight. Fehr *et al.* in [6] point out that regulation of water quality for public heath purposes is essential no matter what the ownership regime is.

In a special issue of *Environment & Urbanization* dedicated to urban water and sanitation in the global south, Budds and McGranahan in [5] provide an overview of global-south privatization activities. Their analysis underlines how unlikely it is that large-scale private-sector firms will deliver water supply and sanitation services to the global poor. They report on the reticence of private-sector actors to extend services to the rural poor, in part due to the seeming impossibility of ever recovering the massive financial investments needed to extend infrastructure from urban centers to impoverished peripheries – roughly \$100 billion over 25 years.

A key conclusion of this line of research is that new paradigms of urban water and sanitation services need to be identified, studied, tested, and promoted. Solo [19] describes one such paradigm: the "'other' private sector" of small-scale entrepreneurial operators that provide water and sanitation services to the urban poor. Here, entrepreneurs deal directly with customers with limited government oversight, ideally, though not always, in competitive settings. Solo [19] estimates that this rapidly-growing sector now supplies roughly 25% of urban water in Latin America and 50% of sanitation services. In Africa, the figures are 50% and 85%. Thus, for an entire continent (Africa) and large portions of the rest of the developing world, small-scale entrepreneurial operators provide the dominant paradigm of water supply and sanitation services; the centralized systems familiar to industrialized nations are little more than an add-on.

This brief discussion of how to frame challenges facing urban water managers underlines the massive intellectual challenge the world faces, with human health and well-being, economic prosperity, ecological sustainability, and billions of dollars of potential investment hanging in the balance. Research is needed at every scale, from global to microscopic. Both cross-training in multiple disciplines and collaboration across disciplines are needed to summon the expertise needed to understand these issues and advance professional practices.

3. The Water Industry as Research Funder/Collaborator

Historically, water agencies have sponsored both applied academic research and research projects undertaken by private consulting firms. Agencies have taken a practical approach, supporting the research they believe will best help them manage their systems. These programs have typically fallen under the disciplines of chemistry, biology, engineering, and finance. As shown above, these disciplines, while still crucial to water management, are just part of the larger picture. Funding agencies are now recognizing this and are moving in new directions with innovative research initiatives. The author is directly involved in the following two initiatives.

3.1. *Example: WateReuse Association and the Human Reaction to Water Reclamation and Reuse*

The WateReuse Foundation (Foundation), based in Alexandria, Virginia, is an educational, nonprofit public benefit corporation that serves as a centralized organization for the water and wastewater community to advance the science of water reuse, recycling, reclamation, and desalination.[1] The mission of the Foundation is to conduct and promote applied research on the reclamation, reuse, and desalination of water. The Foundation's primary sources of funding are its Subscribers and its funding partners, which include the U.S. Bureau of Reclamation, the California State Water Resources Control Board, and the Southwest Florida Water Management District. The Foundation's Subscribers include water and wastewater agencies, and other interested organizations. The Foundation also conducts research in cooperation with two water research coalitions, the Global Water Research Coalition and the Joint Water Reuse Task Force, and other water research organizations in the United States and abroad.

The Foundation's research provides information on the safety and quality of reclaimed and recycled water, and provides water professionals with the tools and knowledge to meet their commitment of increasing the reliability and quality of the nation's water supplies. Historically, this mission focused the Foundation’s research agenda squarely in the realms of biology, chemistry, and engineering. Over the past half-decade, the Foundation has expanded its research interests to include management, economics, and public communication.

In this latter case, the Foundation has sponsored research on human reactions to water reclamation and reuse that have brought together water agency personnel and social psychologists to discuss how society perceives risk and reacts to fears of contamination and contagion [7]. It is a basic research program that could help identify new ways for water agencies to communicate successfully with the public on water quality, supply, infrastructure planning and investment, and other issues. The Foundation could invest as much as $500,000 in this research program over a 3-5 year period. It is likely that research teams will include combinations of academics (social psychologists), consultants, water agencies, and public interest groups. The Foundation signaled its commitment to expanded research in the social sciences by expanding its Research Advisory Committee in early 2005 to include social scientists.

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[1] Introductory materials presented here can be found at http://www.watereuse.org/Pages/foundation.html.

3.2. *Example: Costs and Benefits of Desalination in California*

In 2002, the state of California passed Proposition 50, the "Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002." This initiative set aside funding for competitive grants to study desalination of ocean or brackish waters. Desalination plants remove salt from ocean water and brackish inland water by forcing it through a series of membranes and filters. With more than 7,500 plants operating worldwide, desalination is a proven technology. But it remains expensive and its environmental and social impacts are poorly understood. Nearly all grants funded in Proposition 50's first funding cycle (2005; $25 million) went to pilot desalination projects and technical research. One social-sciences project was funded, entitled "Developing a Tool to Guide State and Local Desalination Planning." The goal of this project is to develop a comprehensive planning tool that communities, water planning agencies, and water providers can use to assess the costs and benefits of desalination relative to other options in their area.

This project takes into account environmental, environmental-justice, and other concerns alongside traditional interests in system reliability and cost. The project will also take a portfolio approach to water resources, building tools to evaluate the value of alternative sources of water to a given region in light of alternative available sources.

A sign of the changing perspective that water agencies are gaining is the list of collaborators and contributors to this project. Table 3 shows both the participants and in many cases, the in-kind financial commitments made to this program. Participants come from nearly every category of stakeholder in water management issues: water agencies, public groups, equipment manufacturers, regulators, and private consultants. Three universities also are involved.[2]

4. Conclusion

Water-management challenges are attaining new levels of importance and complexity. Broad academic engagement is needed if they are to be understood and if ways forward are to be found. Water agencies and regulators are starting to support research in new areas that combine social sciences, natural sciences, and technology research in ways oriented to problem-solving. Public participation, which brings additional information and perspectives to decision-making and helps builds acceptance for outcomes, is also an essential feature of 21st-century water management. This is a promising development in water-related research.

[2] U.C. Santa Cruz is the lead campus; U.C. Santa Barbara and U.C. Berkeley also are participating.

Table 3.Participants in a State-Sponsored Research Project on the Benefits and Cost of Desalination in California.

Public Water Agencies	
	Long Beach Water Department
	Inland Empire Utilities Agency
	Coachella Valley Water District
Private Consulting Firms	
	Stratus Consulting, Inc.
	McGuire Consulting, Inc
Private Water Agencies	
	California American Water Company, Monterey Coastal Division
Regulatory Agencies	
	San Diego County Water Authority
	California Regional Water Quality Control Board, San Diego Region
Non-governmental Organizations (citizen groups)	
	Surfrider Foundation (coastal protection)
	California League of Conservation Voters Education Fund
	Residents of Pico Rivera for Environmental Justice
Private, non-profit funding agencies	
	WateReuse Foundation
Manufacturing companies	
	Poseidon Resources Corporation
Participating Universities	
	University of California, Santa Cruz
	University of California, Santa Barbara
	University of California, Berkeley

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A SUSTAINABILITY SYNTHETIC TERRITORIAL INDEX (ISST) TO ASSESS THE SUSTAINABLE MANAGEMENT OF WATER RESOURCES

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The present work describes the in-progress activities devoted to the definition of a model to assess the sustainable management of the water resources at local scale. These activities partly derive from the EC research project EPSILON "Environmental Policy via Sustainability Indicators On a European-wide NUTS-III level". The objective of the model is to create Sustainability composite indicators starting from elementary indicators of environmental, economic, social and institutional nature. Thanks to proper hierarchical relationships, these indicators are then aggregated in sub-themes, themes and pillars. By means of proper clustering techniques a Sustainability Synthetic Territorial Index (ISST) is finally calculated for each of the regions to be assessed and the model output visualised by means of WebGIS techniques.

1 Introduction and reference scenario

1.1. *Sustainability measure*

The introduction of the concept of sustainability contained in the report "Our common future" [1] has stimulated the start of many studies dealing with the measure of the sustainability.

A system assessing the sustainability of the water resources was elaborated by the Deft Hydraulics Laboratory in the Netherlands [2], that proposed a procedure that allows to evaluate how much a particular planning decision can contribute to the sustainable development. Such procedure foresees five criteria, each of them divided in sub-criteria. Social, economic and environmental parameters related to the public health and to the social welfare are taken into account and equally weighted. The sum of the values of each parameter represents a sustainability index that allows the comparison among different solutions.

Also the multiple risk criteria, measuring reliability, resilience and vulnerability, can be used to assess the sustainability. In this case the sustainability index can be expressed as weighted sum of reliability, resilience and vulnerability, measured for several economic, social, environmental and ecological parameters. Such measurements of reliability, resilience and vulnerability are made through the temporal series of the values that the generic parameter will assume in future time intervals. Such method preliminarily requires the attribution of thresholds of acceptability and not-acceptability of the values assumed by the parameter, thresholds that must be fixed by the analyst and that therefore suffer again of a certain subjectivity, like the discretion residing in the choice of the weight to attribute to each parameter [2].

A different approach to the sustainability assessment is based on the concept of entropy, as a measure to describe the reversibility of the processes, usable also in the problems and in the choices inherent the water resource management. Such approach, proposed by Nachtnebel [3], uses the thermodynamic laws for the assessment of the energy quantity required to bring a system under the initial conditions. Such value can be seen as a useful indicator for the evaluation of the sustainable development.

1.2. *Sustainability indicators*

From several years different bodies and institutions are engaged worldwide to identify a proper set of indicators for the sustainable development.

A first activity consisted in comparing in a synthetic and systematic way the consistent number of indicators defined by the different organizations engaged in this intent:

- To this end, the most important reference is constituted by the international research project EPSILON "Environmental Policies through Sustainability Indicators at European NUTS-III level", a Shared-cost RTD contract awarded in the frame of the "Information Society Technologies" Action of the 5-th Framework Programme of the European Commission. One of the Epsilon project objective was to obtain a synthetic sustainability indicator, foreseeing a hierarchical structure of the indicators, so-called 4x4x4, based on the four dimensions of sustainability, named pillars: environmental, economic, social and institutional. Each pillar is then divided in 4 themes, each theme in 4 sub-themes and finally each sub-theme in one or more elementary indicators and sub-indicators.
- Regarding the data structure of the UN-DSD (United Nations–Division for Sustainable Development) [4], operational structure of the CSD (Commission for

Sustainable Development) active from the Rio de Janeiro Conference of 1992, it is comparable to that of the Epsilon environment pillar.

- Regarding the ECI (European Common Indicators) [5], the EEA (European Environmental Agency) attempts to identify a core set of environmental indicators in which, besides the three themes named air, earth and water, it is present a series of indicators covering from the transports to the energy and also analysing other sectors with a strong impact on the quality of the environment.
- In Italy the Strategy of Environmental Action (SAA) [6], elaborated by the Environment Ministry and approved by the CIPE with Deliberation n. 57 of August 2nd 2002, identifies three sectors of indicators: Nature and Bio-diversity, Natural Resources and Quality of life.

Regarding the structure of the groups or sectors of indicators above mentioned, it is to be pointed out that the number of elementary indicators and sub-indicators related to each group/sector is variable, since each organisation has a different availability of data and a related philosophy of aggregation.

Therefore, it is to be considered that the identification of the indicators is a still open process.

With reference to the scenario just depicted, the present work describes the in-progress activities devoted to the definition of a model to assess the sustainable management of the water resources at local scale, with particular reference to an Optimal Territorial Ambit (ATO). In Italy the ATO is the territorial entity – identified by the National Law 36/94 known as “Legge Galli” from the author’s name – properly set for an optimum management of the Integrated Water System.

According to the Law 36/94, each Italian Regional Government has identified a certain number of ATOs in its own territory of jurisdiction and in the Calabria Region – in Southern Italy – there are 5 ATOs, each of them corresponding to the territory of the 5 Calabrian Provinces. The present case study is relevant to the Calabria ATO-1, having its territory of jurisdiction coincident with the whole territory of the Province of Cosenza, with a surface of about 6,600 square Km, encompassing 155 Municipalities and about 750,000 inhabitants, with a very complex systems of natural water resources and artificial water-related infrastructures.

2 The model philosophy

The universal concept of sustainable development that does not “consume” the available resources, but profitably uses them without reaching their irreversible impoverishment, can be tailored to the sustainable management of the water resources, attempting to define a model that optimises their use, minimises the collectings and the wastes and promotes both the multiple uses and the recovery and the consequent reuse in the agricultural and industrial productive cycles.

Such a complex matter needs to be managed not only in terms of environmental and socio-economical points of view, but also taking into account both the natural systems (the different types of water resources existing in nature) and the artificial systems (those systems artificially set in order to manage the use of the natural resources).

On the counterpart, there are several National Laws (like, in Italy, the Law 319/76, the Law 183/89, the Legislative Decree 152/99, the Law 36/94) and European Directives (like the Framework Directive 2000/60/EC establishing a framework for Community actions in the field of water policy) that have defined a reference framework for all the actors involved in the management of the water resources.

In virtue of the above mentioned considerations, a proper structure for the indicators has been adapted to the sector of the management of the water resources, starting from those described in the previous section.

The number of the sustainability dimensions has been set to three, compared to the original four dimensions of the 4x4x4 model of the Epsilon project and of the 4-spheres model of the UN-DSD. The corresponding three pillars of the sustainable management of the water resources are:

- 1ST PILLAR:ARTIFICIAL SYSTEMS (ASA).
- 2ND PILLAR:NATURAL SYSTEMS (ASN).
- 3RD PILLAR:SOCIO-ECONOMIC-INSTITUTIONAL (SEI).

The corresponding structure is shown in Figure 1, in which the ISST (Sustainability Synthetic Territorial Index) is subdivided into the three above mentioned pillars, each pillar in themes, each theme in sub-themes and, finally, each sub-theme in elementary indicators.

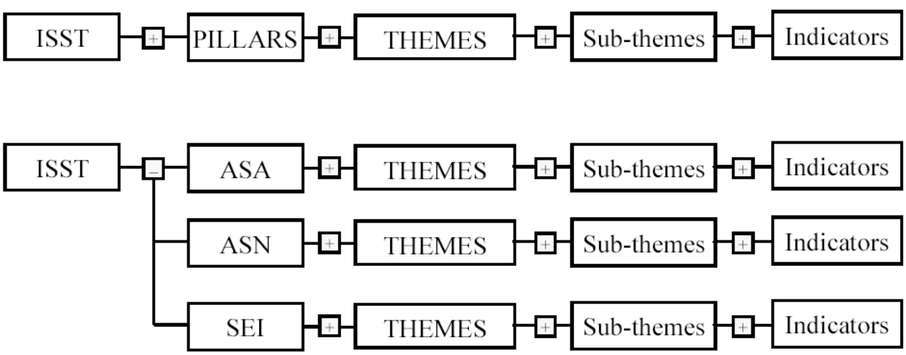

Figure 1. A collapsed structure of the sustainability model.

2.1. *The ASA (Artificial Systems) pillar*

The structure of the ASA (Artificial Systems) pillar, entirely shown in the Figure 2, is based on the Italian Law 36/94, that re-organises the Integrated Water System.

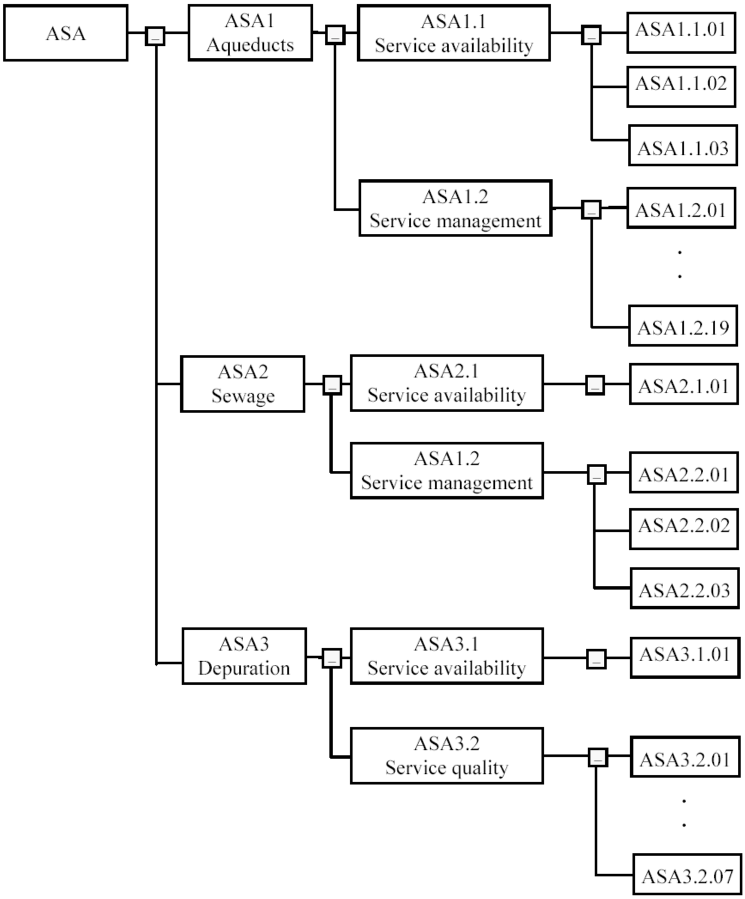

Figure 2. The ASA (Artificial Systems) pillar whole structure.

2.2. *The ASN (Natural Systems) pillar*

The structure of the ASN (Natural Systems) pillar, schematically shown in the Figure 3, has been derived from a cross-comparison between the Framework Directive 2000/60/EC and the Italian Legislative Decree 152/99, analysing the common parts of the two documents relevant to the definition of the policies and the quality objectives for all the water bodies and the identification of proper monitoring procedures. It is to be pointed out that some of the indicators shown in the Figure 3 are further subdivided in sub-indicators. In order to avoid to include the full list of the 99 indicators + 70 sub-indicators and in order to give an example of the nature of some of them, the indicators/sub-indicators relevant to chemical and bacteriological elements consist of the concentration of the pollutant substances, whilst the indicators/sub-indicators relevant to physical and hydro-morphological elements consist mainly of temperature, salinity, pH, transparency, conductibility, dissolved oxygen, depth.

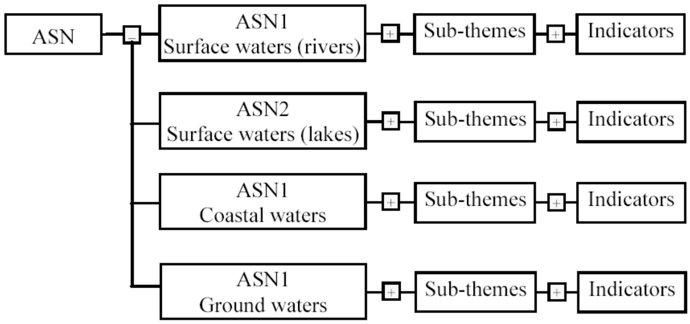

Figure 3. The ASN (Natural Systems) pillar schematic structure.

2.3. *The SEI (Socio-Economic-Institutional) pillar*

The socio-economic-institutional pillar dimension has been deduced by the study [7] carried out by the Working Group 2.6 "Wateco", one of the ten working groups established by the European Parliament and the European Commission with the objective to define a Common Strategy of Implementation for the Waters Directive 2000/60. In particular, the Wateco Working Group is dealing with the economic aspects of the Directive.

Starting from the results of this study, a further re-tuning of the pillar structure has been made, as, for instance, the suppression of some of the "Wateco" elementary indicators, due to their inapplicability to a local geographical context (effects of the trends of macro-economics policy at national level or higher) or simply to avoid redundancy with very similar indicators already present in the ASA pillar. At the end of this process, 37 elementary indicators have been grouped into 12 sub-themes and finally into the 3 themes. The corresponding structure is shown in the following Figure 4 and Table 1.

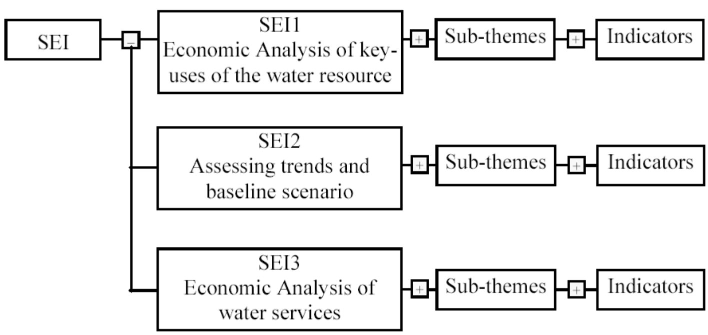

Figure 4. The SEI (Socio-Economic-Institutional) pillar schematic structure.

Table 1. The SEI pillar structure with all the elementary indicators.

Theme code	Theme name	Sub-theme code	Sub-theme name	Indicator code	Indicator name
SEI.1	Economics Analysis of key water uses	SEI.1.1	Agriculture	SEI.1.1.01	Total cropped area
				SEI.1.1.02	Cropping pattern
				SEI.1.1.03	Livestock
				SEI.1.1.04	Gross production
				SEI.1.1.05	Income
		SEI.1.2	Industry	SEI.1.2.01	Employm. for key sub-sectors
		SEI.1.3	Hydropower	SEI.1.3.01	Installed power capacity
				SEI.1.3.03	Electricity production
		SEI.1.4	Navigation/ Transport	SEI.1.4.01	N° of boats through key points per year
				SEI.1.4.02	Employm. linked to navigation
				SEI.1.4.03	Quantity and value of goods transported
				SEI.1.4.04	Quantity and value of goods through key harbours
				SEI.1.4.05	Employment linked to harbour activities
		SEI.1.5	Gravel extract.	SEI.1.5.01	N° of extracting companies
		SEI.1.6	Fish farming	SEI.1.6.01	Number of fish farms
		SEI.1.7	Water-related tourism	SEI.1.7.01	Total number of tourist-day
				SEI.1.7.02	Total employment and turnover in the tourism sector
		SEI.1.8	Flood control	SEI.1.8.01	Total population protected
				SEI.1.8.02	Total turn-over of protected economic activities
SEI.2	Assessing trends and baseline scenario	SEI.2.1	Trends in exogenous variables	SEI.2.1.01	Population growth
				SEI.2.1.02	Changes in economic development (DGP change)
				SEI.2.1.03	Changes in water pricing policies
				SEI.2.1.04	Technological changes
		SEI.2.2	Planned policies and investments	SEI.2.2.01	Proposed invest. in water supply and wastewater treatm.
				SEI.2.2.02	Proposed invest. in pollution reduction programmes for agriculture
				SEI.2.2.03	Proposed investments in flood protection
				SEI.2.2.04	Proposed investments in wetland restoration
				SEI.2.2.05	Proposed investments in improved technology
				SEI.2.2.06	Proposed investment in water supply enhancement
				SEI.2.2.07	Other program. and measures
SEI.3	Assessing cost-recovery	SEI.3.1	Prices for water services	SEI.3.1.01	Current water price level
				SEI.3.1.02	Current water price structure
		SEI.3.2	Financial costs of water services	SEI.3.2.01	Capital costs
				SEI.3.2.02	Operation and maintenance
				SEI.3.2.03	Administrative costs

The total number of indicators for the three dimensions of the sustainable management of the water resources is synthetically shown in the Table 2.

Table 2. Number of indicators for a sustainable management of the water resources.

	ASA	ASN	SEI
Theme	3	4	3
Sub-themes	6	13	12
Indicators	34	101	37

Even though a detailed description of all the indicators is beyond the scope of this work, it is to be underlined that the whole structure of the adopted sustainability model has been derived from proper legal frameworks and therefore benefits, from one side, of an increased robustness in terms of scientific rationale and concrete applicability and, from the other side, of a potentially increased availability of the data, thanks to the procedures and the instruments institutionally defined in order to operationally comply with the legal prescriptions.

3 The aggregation technique

A composite index is a synthetic index obtained from a set of different elementary indicators, aggregated through more or less complex mathematical relationships allowing to resolve multidimensional problems. The use of composite indexes allows to have a complete and synthetic picture of the phenomenon that is being analysed, facilitating its analysis and supporting the comparison and the classification of different realities.

The study of composite indicators has received an increasing attention in recent years and several methodologies have been developed to handle different aspects of the issue.

An exhaustive insight into the subject is given in [8] and [9].

According to the adopted model structure, the construction of a composite indicator necessarily has to be done following different levels of aggregation, taking into account a horizontal dimension, in which the parameters are normalized, and a vertical dimension, in which the normalized data are weighted and composed, as shown in the following Figures 5 and 6.

With reference to the Figure 6, the data pre-processing consists of three main steps: 1) a quality check on the data, disregarding those with evident errors; 2) a detection of the missing data, filtering out the corresponding records; 3) a rectification of the indicator direction, assigning – before the normalisation and aggregation steps – a multiplication factor of -1 to those indicators moving in a direction opposed to sustainability (for instance, the indicator of the losses in a water distribution network has to be rectified, since higher values – i.e. high losses – move away-from and not toward-to sustainability).

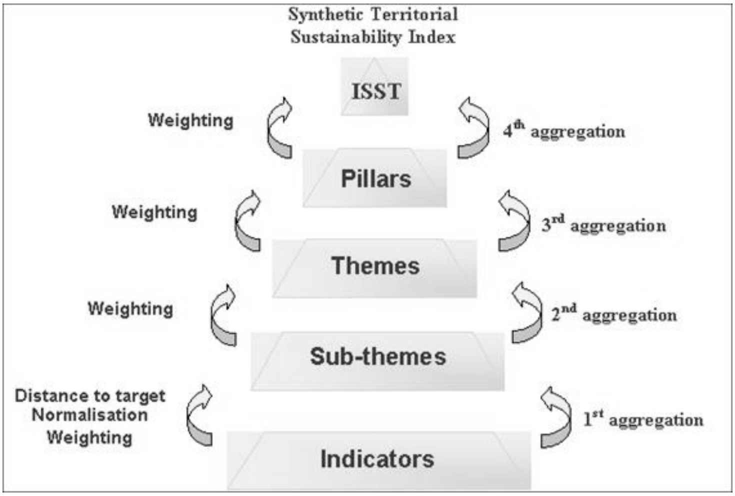

Figure 5. Building a composite indicator.

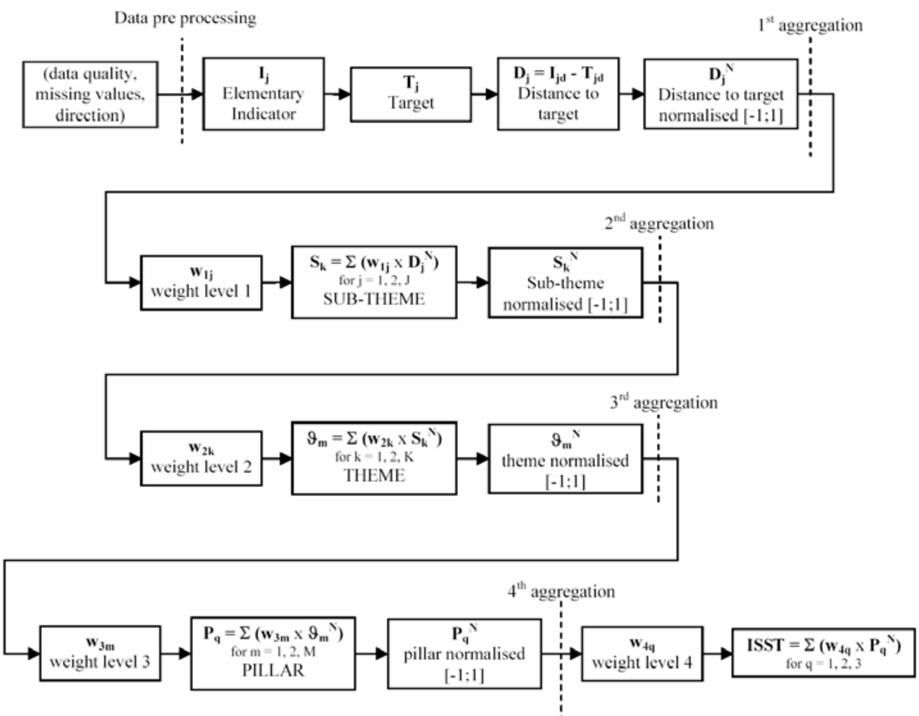

Figure 6. Composite indicator flow-chart.

4 The normalisation methodology

Among different normalisation methods available in literature (multiple linear regression models, Z-scores, min-max, Principal components analysis and factor analysis, Cronbach alpha, Neutralization of correlation effect, Efficiency frontier, Distance to targets, Experts opinion (budget allocation), Public opinion, Analytic Hierarchy Process), in the present work the distance-to-target method has been selected, because a careful definition of the different targets, even though is a difficult tasks, it allows to directly measure the effectiveness of the adopted sustainability policies.

As an example, in the following Table 3 are shown the 22 targets defined in correspondence of the 22 elementary indicators of the ASA1 theme "Aqueducts".

Table 3. Name, code and target value of indicators for the ASA1 theme "Aqueducts".

Indicator code	Indicator name	Measurement unit	Target
ASA.1.1.01	Storage capacity	mc	available mc > 100% daily average volume delivered
ASA.1.1.02	Water gross daily availability	l / inhabitant / day	260 if population < 5000 280 if 5000 < pop. < 10000 300 if 10000 < pop. < 50000 320 if 50000 < pop. <100000 340 if pop. > 100000
ASA.1.1.03	Service coverage	%	100%
ASA.1.2.01	Potabilization plants: age of civil buildings	year	< 40 years
ASA.1.2.02	Potab. plants: condition of civil buildings	poor / suff./ good	Sufficient
ASA.1.2.03	Potabilization plants: age of electro-mechanical install.	year	< 10 years
ASA.1.2.04	Potabilization plants: condition of electro-mechanical installations	poor / suff./ good	Sufficient
ASA.1.2.05	Potab. plants: tele-management availabil.	yes / no	yes
ASA.1.2.06	Pumping plants: age of civil buildings	year	< 40 years
ASA.1.2.07	Pumping plants: condition of civil build.	poor / suff./ good	Sufficient
ASA.1.2.08	Pumping plants: age of electro-mechanical installations	year	< 10 years
ASA.1.2.09	Pumping plants: condition of electro-mechanical installations	poor / suff./ good	Sufficient
ASA.1.2.10	Pumping plants: tele-management availability	yes / no	Yes
ASA.1.2.11	Age of storage tanks	year	< 60 years
ASA.1.2.12	Condition of storage tanks	poor / suff./ good	Sufficient
ASA.1.2.13	Storage tanks: tele-management availabil.	yes / no	Yes
ASA.1.2.14	Water-meter installed along water systems	%	water-meter for each consum.
ASA.1.2.15	Absolute average losses for distribution water systems	l / sec / Km	0,25 l / s / Km of network
ASA.1.2.16	Average losses in % for distribution water systems	%	20%
ASA.1.2.17	Age of distribution water systems	year	< 60 years
ASA.1.2.18	Conservation of distribution water systems	poor / suff./ good	Sufficient
ASA.1.2.19	Distribution water system: tele-management availability	yes / no	Yes

The above mentioned targets have been taken directly from the most binding available document in terms of water policies at local level, the ATO-1 Calabria Ambit Plan [10]. According to the legal framework of the Law 36/94, this Strategic Plan, based on a very detailed inventory of all the water-related infrastructures, identifies the planning for future investments and intervention and outlines the management and organisational model together with the financial-economic plan.

5 Results

In this section are shown the preliminary results of the first case study, relevant to the Calabria Optimum Territorial Ambit ATO-1. Its territory of jurisdiction is coincident with the whole territory of the Province of Cosenza in Southern Italy, shown in Figure 7, with a surface of about 6,600 square Km, encompassing 155 Municipalities and about 750,000 inhabitants.

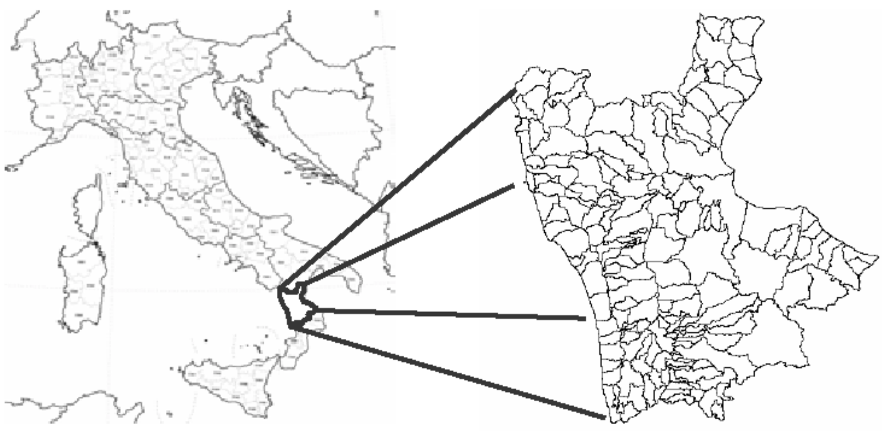

Figure 7. Optimum Territorial Ambit Calabria ATO-1.

Due to the very time-consuming and effort-consuming activities relevant to the data collection, this first model application is now limited to the ASA pillar.

Nevertheless, even though this application is now limited to only few indicators, it is fully representative of the conceptual model and it will be extended to other and/or updated indicators as soon as the corresponding data will become available.

The data source is represented by an inventory of the water related infrastructures of the Calabria ATO-1 and the data are relevant to the year 1998.

With reference to the previous Figure 2, the data relevant to the elementary indicators ASA1.1.02 (water gross daily availability), ASA1.2.15 (absolute average losses for distribution water systems) and ASA1.2.16 (average losses in percentage for distribution water systems) have been collected and processed according to the procedure outlined in the Figures 5 and 6, using the proper targets defined in the Table 3 and unitary weights in the first two aggregation steps.

The composite values for the ASA1 theme have then been clustered in the following 5 categories:

- Very low (-1 ≤ values < -0,6).
- Low (-0,6 ≤ values < -0,2).
- Medium (-0,2 ≤ values < 0,2).
- High (0,2 ≤ values < 0,6).
- Very high (0,6 ≤ values ≤ 1).

The mathematical processing has been implemented in a MS Access RDBMS (Relational Data Base Management System) and the GIS has been developed in ArcGIS 9.0 environment.

In the following Figure 8 is shown the GIS output map of this test application, in which 18 of the 155 Municipalities have been filtered out from the final categorisation, due to partial data unavailability or due to poor quality data.

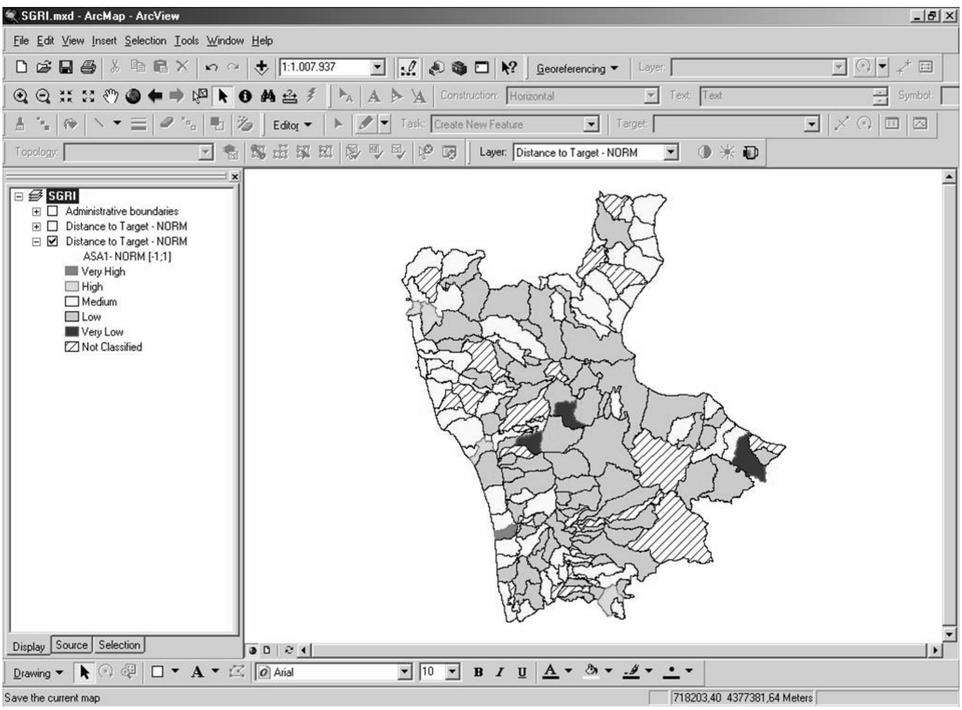

Figure 8. GIS output map of ASA1 theme “Aqueducts” test application.

The developed tool exhibits high versatility, being able to generate different user-driven scenarios according to the availability of new and/or updated data and/or targets or simply varying the weights in the aggregation steps.

Remarkable is also for instance the possibility, shown in Figure 9, to obtain output maps and related geographical information of single elementary indicators which are above/below the corresponding target.

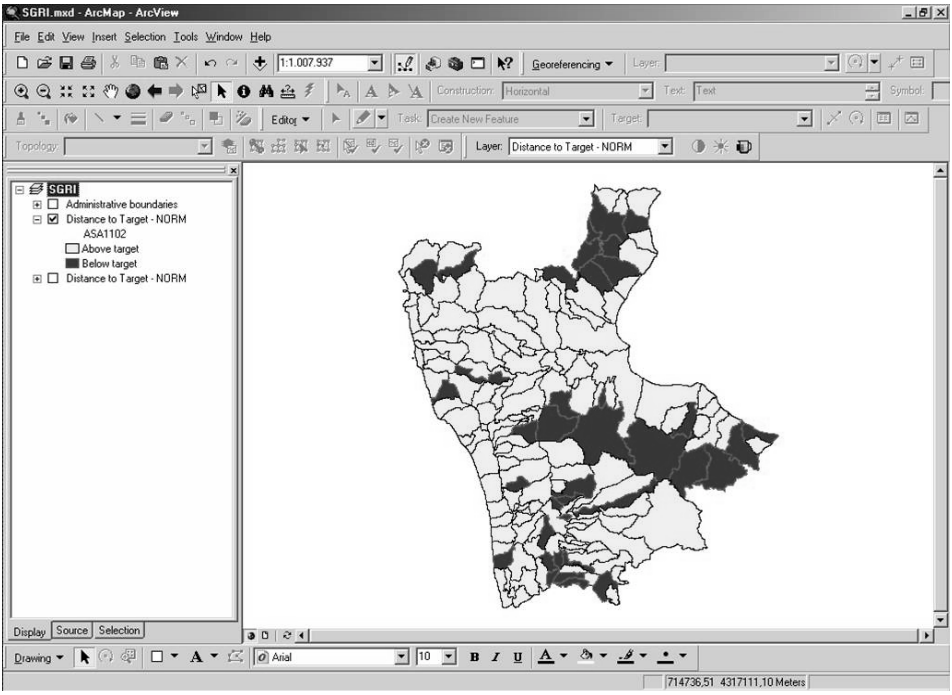

Figure 9. GIS output map of Municipalities having ASA1102 indicator above/below target.

6 Perspectives and conclusions

Despite the completeness of the sustainability model above described, its application and validation in ATO-1 Calabria is still in progress, due to the very time-consuming activities related to gathering all the data. Nevertheless, it represents an advancement in comparison to the state of the art, for three main reasons:

- It sensitively reduces the characteristic limit of the previous models related to the analyst's subjectivity, since the measurement unit of the single indicators is given by its distance to the corresponding target, being the latter properly and objectively fixed according to the national and international legal frameworks of the sector.
- It is well applicable to a local scale of Optimal Territorial Ambit.

- The social-economic dimension of the sustainability, being strongly correlated with the Waters Directive 2000/60, exhibits a strong link with the social-economic implications of the European waters policies.

In virtue of the previous considerations, the most interesting perspectives are certainly related to the possibility that the managers of the Integrated Water Systems can use the model as a decision support tool able to measure the effectiveness of the adopted sustainability policies, as well as a scientific tool to build-up validated parametric structures, acknowledged by different planning institutional organizations. In particular, the characterization of sustainability indicators referred to the management of the water resources allows a quick evaluation of the management actions to be activated for the use and the reuse of the waters with reference to the different uses and the different scenarios of the Integrated Water System.

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WATER RESOURCES – CROATIAN COMPARATIVE ADVANTAGE

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Water resources get the growing importance in development projects in Republic of Croatia, partly because of the general trend around the world, where the drinking water gets strategic values, and also because of consciences of all participants in the use of space on the home scene about the importance of water resources in the future development of the country. Croatia is generally talking rich with surface and ground waters, but the large part of water reserves inflow and run out by large rivers. Long summer dry periods bring the problems of available water quantities, especially in the Adriatic area. Consequently, in spite of water wealth, Croatia just with the good knowledge about water resources and efficient management can consider about the water as the comparative advantage in future development. Researchers more and more work on defining of water reserves, which as the surplus on the necessary reserves can get economic values and have been included in the future water business. This paper presents the situation with water resources in Croatia, problems how to ensure quantity and quality and some ideas how can water resources become advantage in future development of the country.

1 Introduction

Republic of Croatia enters in the order of European countries, which can be considered as the rich with the water resources, especially from the reason that water resources are generally of very good quality. According to different UN declarations ''water is public good'' and uses foremost for the water supply of own population and covering the needs of energy production, irrigation etc in the country where are located. However, world so and Croatia increasingly consider about the commercialisation of part of water resources and export of water in areas where it lacks. Anyway the water becomes more and more comparative advantage of countries with the quantities, which overpass the need of own development. Due to present knowledge Croatia has a chance to transform a part of water resources in comparative advantage within the development of whole Mediterranean, which has a lot of problems with the insurance of sufficient quantities of potable water.

How does seem the general picture of the ''water wealth'' of Croatia? Due to water balance from Water Management Plan, Croatia has at its disposal in total about 5000 m^3/s of renewable water reserves. This is the average yearly quantity, which outflow from the territory of Croatia, including the transboundary water of divided management. In total this is around 35.000 m^3 yearly per capita. In this quantity are includes and renewable groundwater reserves, which Croatia has around 2.050 m^3 yearly per capita. Consumption of Croatian population is relatively low in respect to total renewable reserves, and brings out only 3,8% of total own water resources, and due to available groundwater reserves around 11%. For the production of electricity was engaged in total about 27% of water resources, but this water returns in the natural system without larger quality changes.

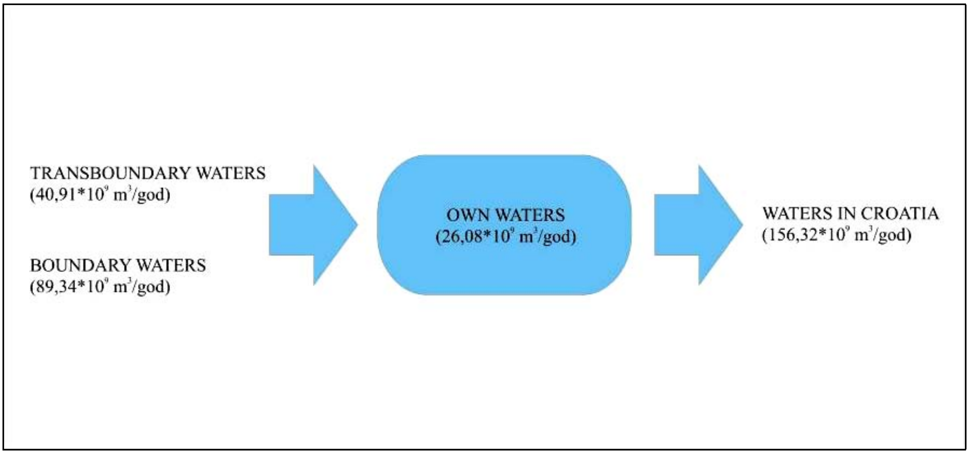

Figure 1. The average water balance of Croatia for the period 1961-1990 (towards WMP).

Quoted total water reserves are fascinating for so small country such as Croatia, but the situation nevertheless is not so simple, because climatic conditions and requirements of keeping up stable ecologic state in the space does not enable the use of total water reserves. In total reserves are include high water waves (floods) which create large problems, which all want to get rid of as fast as possible. Consequently, water resources management is the multi layer problem, which demands exceptional knowledge about natural system, and every intervention in water resources needs to be observed through possible changes of entire ecosystem. This is more complex approach than used earlier, when decisions about the interventions in water resources have brought mainly with one-sided interest decisions. Such approach has brought on one side the benefit, but in many cases long term problems in the space.

In the Introduction needs stress that Croatia considering water resources is generally divided in two parts. Firstly are the water resources of north Croatia, which belong to the large Pannonian basin, with largest Croatian rivers Sava and Drava and Danube, which is mainly the border river between Croatia and Serbia and Montenegro. In the part of Crotia, which belongs to the Pannonian basin in the geologic structure prevails the complex of Neogene mostly clastic rocks, which is the reason of prevailing surface outflow, and along the rivers Sava and Drava forming of relatively deep alluvial basins, in which prevail gravel layers rich with water [2]. South from Karlovac depression towards Adriatic Sea extend the karst area of Dinarides. Surface streams are not so well branch out as in the Pannonian basin, because the largest part of precipitations infiltrate in karst underground. Different types of aquifers require different accesses and knowledge in the research and water resources management. Water divide between Adriatic and Black Sea catchments extends through the mountain area of Dinarides, so the part of karst areas belong to Balck Sea catchment and the largest part to Adriatic catchment [4].

Needs stress that the large part of water resources are in the underground and this is the reason that almost 90% of the public water supply in Croatia has been connected on groundwater. Research of water resources in Croatia have followed the happenings on the scientific scene in Europe, especially during the period when Croatia had been the part of Austria-Hungary monarchy, so the first organized forms of water supply in Croatia were established in second part of 19th century, when started gradual industialization of towns and when towns had come out from the middle century walls. This primarily had been connected for large towns and city as Zagreb, Rijeka, Pula, Šibenik, Split, Varaždin etc. It is known that Split has had the water supply system from the Roman time (Diocletian) and Dubrovnik a little bit later. On Skradin Buk has been built one from the oldest hydroelectric power stations in the world (1985), what also shows how our people have thought about the use of water resources in the development of the country. Especially interesting area for researchers have been karst, where numerous Austrian, German, Hungarian and Croatian researchers had created the world terminology for karst environments, which is still used in the literature. However, neither separation from Austria-Hungary morachy has not brought the decrease of research activities in our space, because regardless on certain loosing connections with the develop part of the Europe, it was necessary to organize the life of growing towns. It is specially related on the period after II. World War, when many of hydroelectric power plants have been built, and when growing towns needed to be covered with quality water supply systems. Maybe the largest standstill in the research and water works emerged during and after Croatian War of Independence, because all the financial possibilities were directed on reconstructions of war destroyed objects. We think that in next three years will happen the important change, because the development requires special attention in the field of water resources protection, surely the most significant part of water resources management. Adjustment of our regulations about water with EU Directives for water [11] requires certain restructuring of existing management system and additional knowledge, which will enable efficient usage and water resources protection in Croatia. Aside of that, in next period can be expected commercialisation of the part of Croatian water resources and including of Croatia in world water business. For these steps Croatia is preparing by on going project for definition of free ''water capacities'', evaluation of the quality of these capacities, protection and way of including on the water market at the Mediterranean level.

2 Climatic Characteristics

Croatia has been placed in the moderate climatic belt, but with expressed influence of Mediterranean climate in the Adriatic coastal area, and typical continental climate in the continental part of Croatia. For development of water resources the most significant parameters are precipitations, air temperature and direction and intensity of wind.

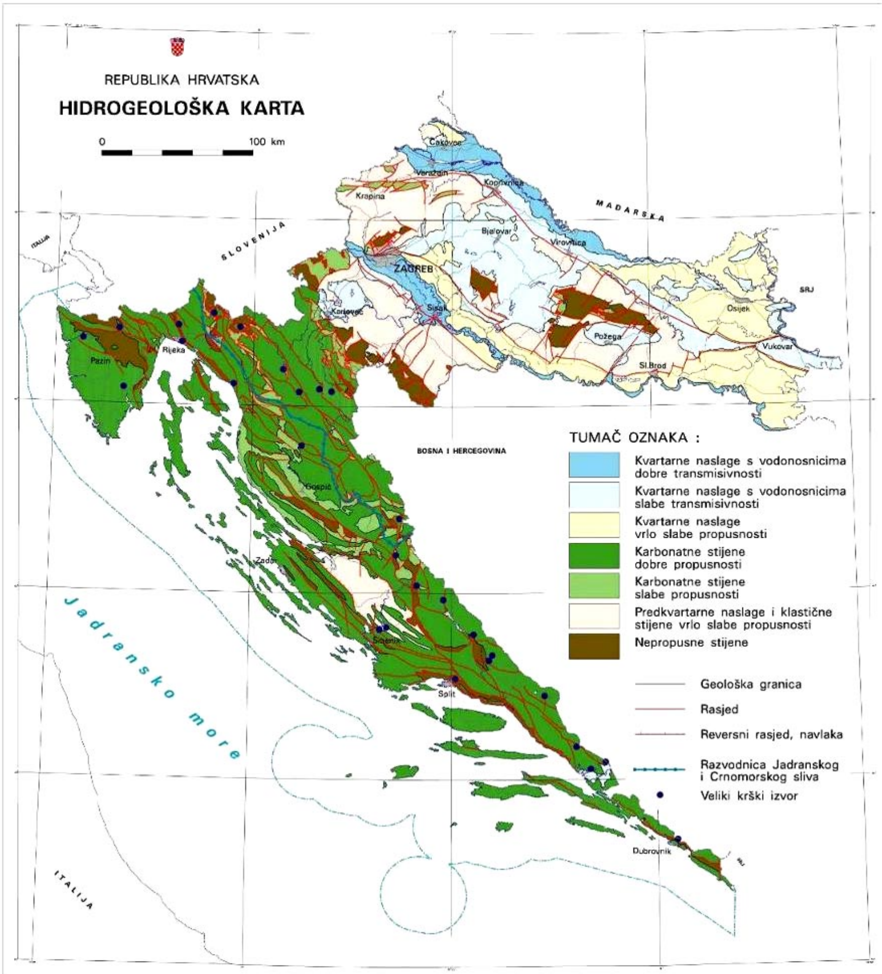

Figure 2. Presentation of different types of aquifers in Croatia.

From the precipitation map is visible that the Adriatic coastal area and islands have yearly between 800 and 1200 mm of precipitation, that quantity in high mountainous area of Dinarides, especially in the north Adriatic area grow over 3500 mm, and that towards inland of the country quantity of precipitation gradually diminish on below of 1000 mm yearly. Such distribution of precipitation clearly shows that the main concentration of water is connected for karst area of Gorski Kotar and Lika, and that the highest water quantities in southern part of Dinarides are binded for high mountainous area in the neighbouring states (Bosnia and Hercegovina). Needs mention that it is in the same time the area of water divide between Adriatic and Black Sea catchments, and that these large water reserves are drained on surface or underground towards one and other catchment.

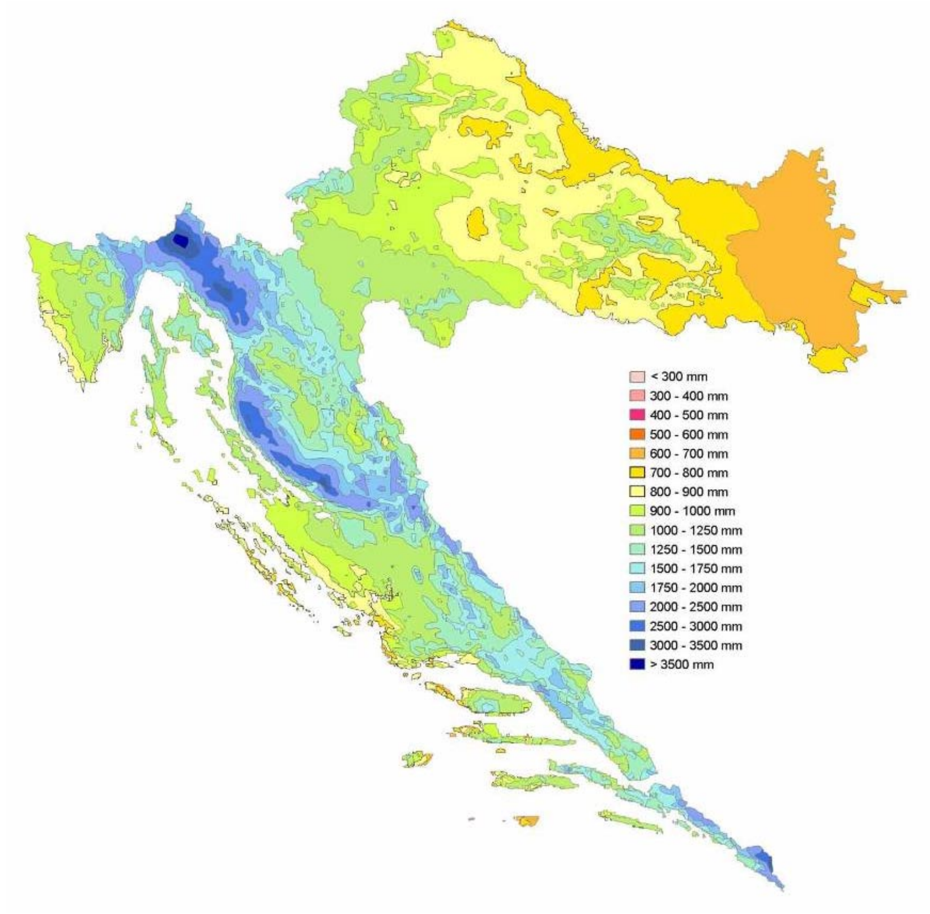

Figure 3. Average yearly precipitations (1961-1990, towards WMP).

The map of temperature changes shows the similarities with the precipitation map, but with negative mark. With altitude growth the average yearly temperature diminish to the level of about 2°C on the highest mountain area of Gorski Kotar and Lika. Coastal area and islands are in the range from 14 to 18°C, and continental part in Pannonian basin around 10°C.

Wind is also one of the most significant climatic elements, which influence on water resources. Foremost is the size of evapotranspiration, which considerably influences on total water quantity in the space. Croatian territory is marked with large diversity. While in the Adriatic area and part of mountain area along the coast prevails Mediterranean and local conditions with dominating South winds and "bura'', in the continental area are the typical middle European conditions with west, south and northeast winds.

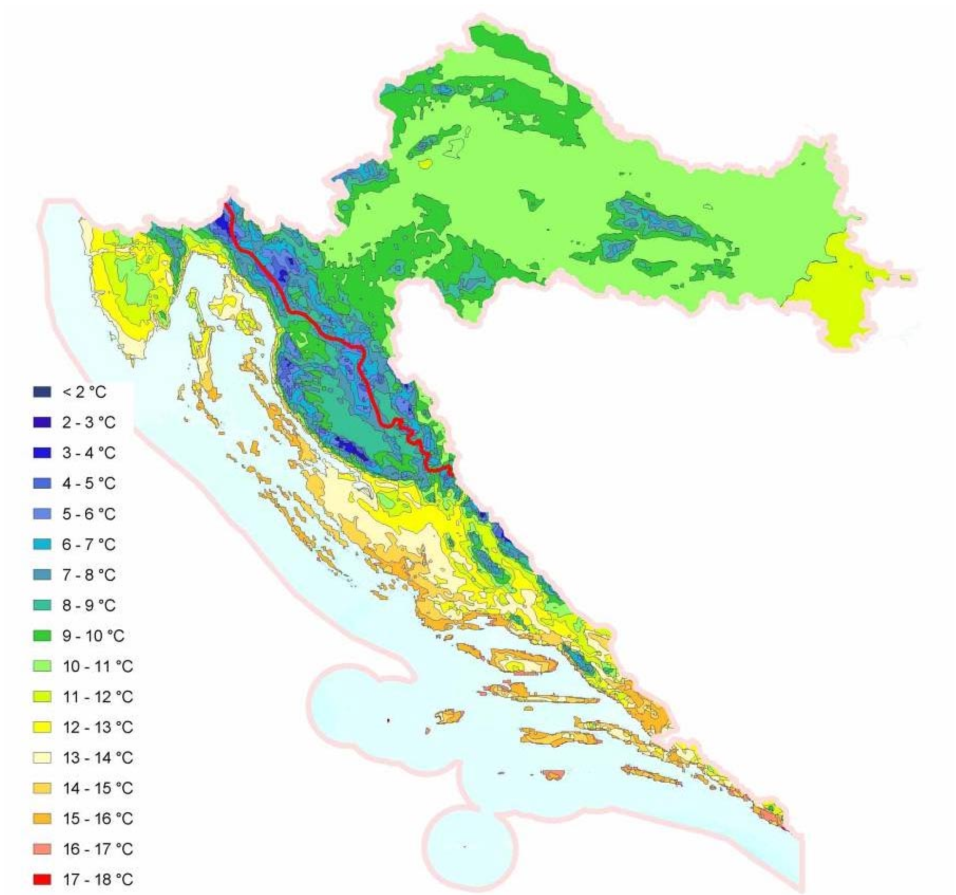

Figure 4. Average yearly air temperature (1961-1990, towards WMP).

3 Water Resources Guidelines

3.1. *Pannonian Basin*

In the Pannonian area dominate the Drava, Sava and Slavonian depressions, in which are deposited thick sediments of porous loos and semi consolidated layers of Quartenary ages. Depression of Drava river has been filled with the large mass of layers formed by erosive activities of Drava river with the characteristic enlargement of grain size towards the surface, what have had the influence on the improvement of hydrogeological characteristics of layers in the zone of potential intervention in groundwater.

Drava river with the left tributary Mur river has characteristics of north Alpine rivers, stabile flow during summer periods, when melt the large amount of snow and ice in Alps. The average yearly flow rate at Belišće gage station is 558 m^3/s. On the river Drava in Croatia were built 3 hydroelectric power plants (Varaždin, Čakovec and Dubrava), which partly have been regulated downstream part of river. Planned HPP Virje is under the design and waits agreement with Hungary.

Public water supply has absolute advantage in the use of water resources and all other activities, which multi purposely include public water supply. When speaking about water resources in Croatia the special attention has to be given to groundwater, which in Croatia covers around 90% of public water supply. Important underground aquifers are formed along Drava river, which looking from the surface give the impression of the uniqueness, but research of underground shows the diversity, which has the direct influence on a way and quantity of water usage.

From the cross section is visible that that the whole aquifer can be divided in two parts. Firstly is the Varaždin aquifer of maximal depth around 100 m, which is formed after entry of Drava river in Croatia, and becomes thinner on the threshold by Koprivnica. After the threshold aquifer again becomes deeper up to the mouth of Drava river in Danube river. The aquifers are lithologically essentially differ. In the Varaždin aquifer prevail course grain sediments (gravel), and after crossing the threshold by Koprivnica begin prevailing of fine grained components (sand and dust). It means that the Varaždin aquifer has exceptional hydrogeologic characteristics with the possible high specific yield, and aquifer downstream Koprivnica is much more poor. This is the main reason that town of Osijek must for its public water supply use treated water from Drava river. Needs to stress that the Varaždin aquifer is exceptionally rich with water, but with considerable negative influence of agriculture on the quality of water because of very thin cover impermeable sediments.

Similar is the situation with the aquifer along Danube river in Croatia, where were sedimented large mass of low permeable eolic layers. Groundwater exploitation has been connected for limited aquifers inside fine grained complex of sediments of large thickness. Danube river influence on groundwater is not significant.

Sava is longest and largest Croatian river, which at Bregana enters in the Croatian territory, and from Jasenovac is the border river with Bosnia and Hercegovina. For the illustration of the size of river it is necessary to point out that the yearly average flow at Zagreb is 323 m^3/s and before excite from the state at Županja is 1169 m^3/s. Consequently the river from Zagreb to Županja increase the flow rate for about 3,5 times, mostly from the area of Dinarides in Croatia (Kupa, Una) and Bosnia and Hercegovina (Vrbas, Bosna). On the Sava river in Croatia there is no built any hydroelectric power plant, but exist plans for the construction of 3 steps in the wider area of Zagreb (Podsused, Prečko and Drenje). Quoted storages have the multiple purpose, basic are the production of electricity and the regulation of Sava river in the city of Zagreb, which would enable the urban development of the city along the river. The important advantage of planned dams are related to the improvement of hydrogeological values of underground aquifers along the river, from which city gets the potable water.

Along the Sava river are as well as along Drava river formed aquifers, which hydroulic values are diminished going downstream because of enlargement of fine grained components in aquifers. From Slovenian border to Sisak has been formed the deep underground aquifer on both sides of river, differentiated in the Samobor aquifer up to the threshold in Podsused, from where gradually increase the depth to the area of Črnkovec near Zagreb (around 100 m), and again decrease the depth towards Sisak (Figure 6). At the area of Sisak river again over flow threshold and aquifer towards Županja holds the depth of about 50 m. Needs emphasize that for aquifer along Sava river is connected the water supply system of the city of Zagreb (around 5 m^3/s). In the wider are of the city of Zagreb are present a lot of problems with insurance the quality of water because of urban and industrial extension of the city on the aquifer. Numerous former extraction sites are because of the disrupted quality abandoned, and we have situation of constantly opening of new sites in marginal parts of city. Unfortunately, neither these areas are not anymore sure, so former potential groundwater extraction sites are today inside urban areas. Solutions could be in the investigation of deeper parts of aquifers.

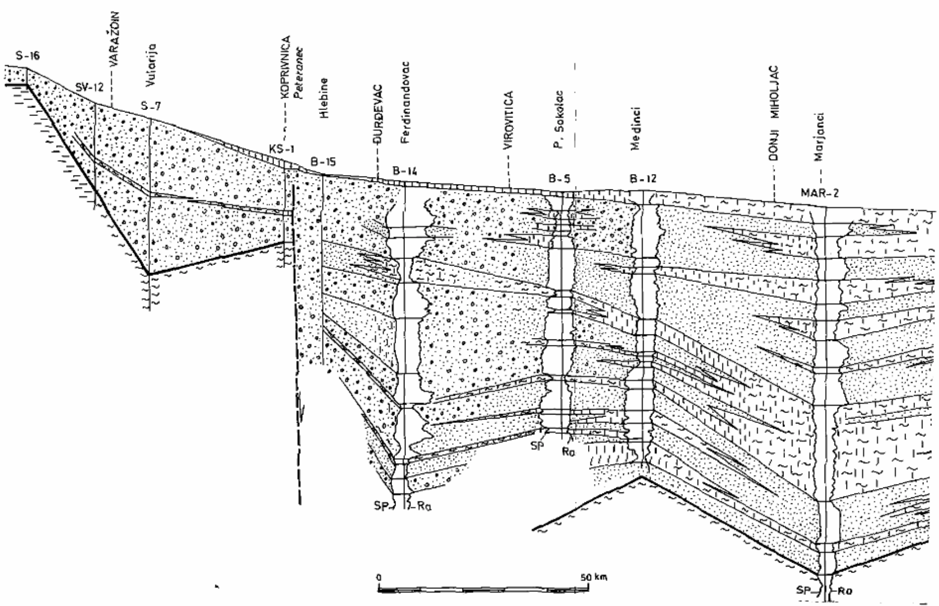

Figure 5. Longitudinal cross section along Drava river from Slovenian boundary towards the mouth in Danube river.

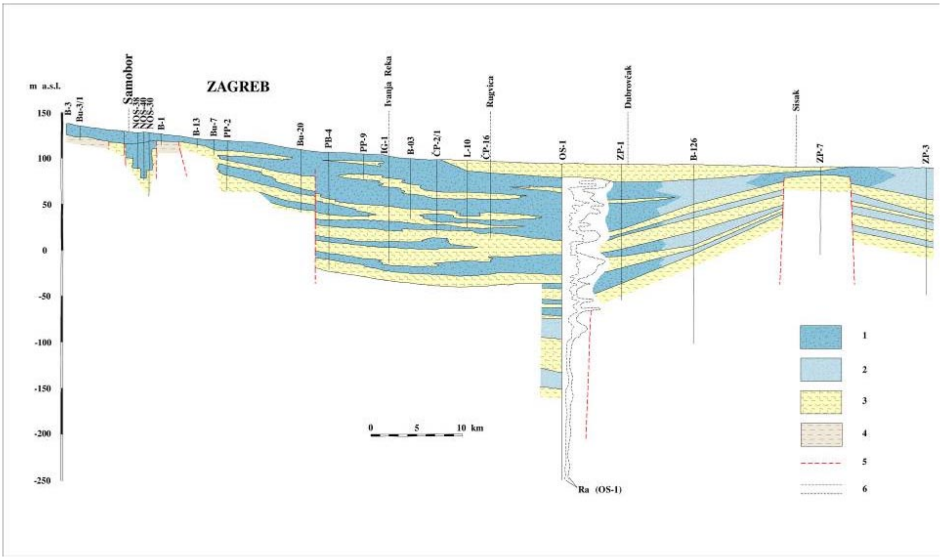

Figure 6. Longitudinal cross section along Sava river from Sovenian border to Sisak (LEGEND: 1 - very high permeable layers, 2 -high permeable layers, 3 -permeable layers, 4 -impermeable layers, 5 - fault, 6 – borehole).

3.2. *Karst Area and Dinarides*

More than half part of the country has been built from karstified carbonate rocks. This is mainly the mountain area of Dinarides, the area of specific development of karst forms and significant reserves of high quality of potable water [9,10]. The whole mountain area is very rich with precipitation, but with expressed problem of the irregular seasonal distribution and relatively low retention abilities of karst aquifers, what causes on one hand long summer dry seasons, and on the other hand fast out flow of large quantities of surface and underground water. Consequences are the problems with water quantity even on present level of demand and very often floods in rainy seasons. Decrease of draining towards karst springs in coastal areas provoke the effects of sea influence on many locations along the coast, and some potable water springs are salinized and completely out from water supply systems [1,6]. In spite of natural difficulties needs to emphasize that karst aquifers in Croatia are mainly of exceptionally high quality and present the value, which in the future can bring considerable economic advantages in respect to other European countries.

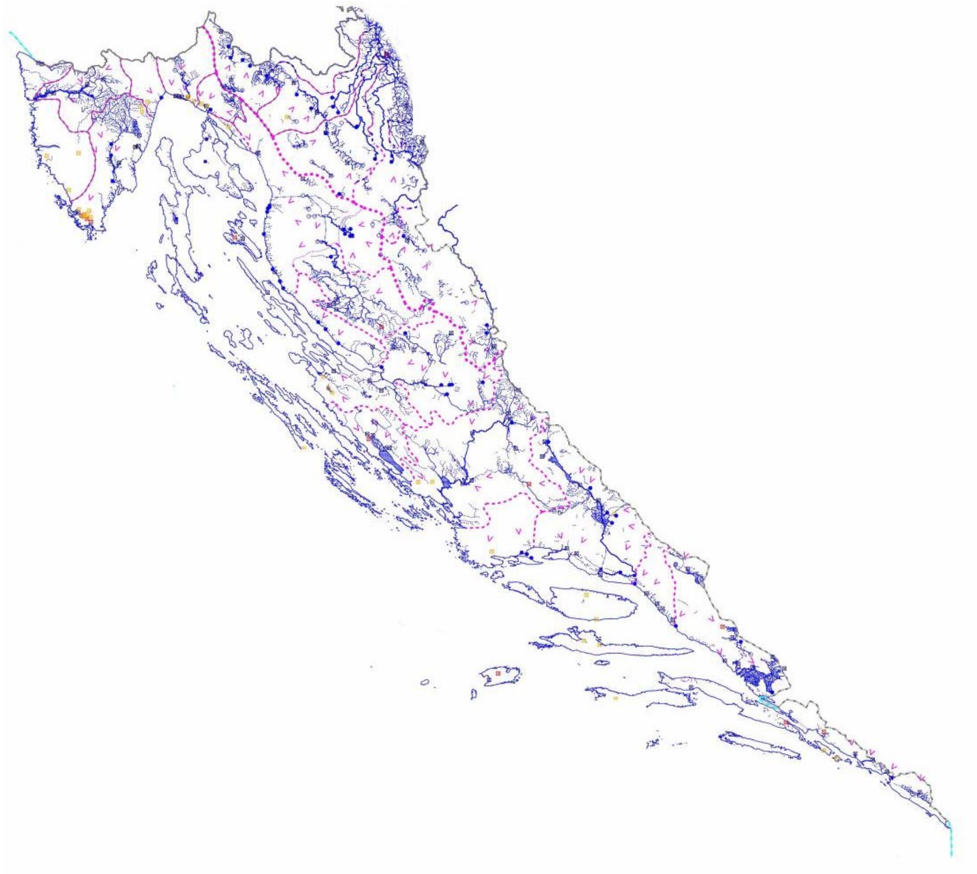

Figure 7. Water resources in karst area in Croatia.

It is important to mention that in the natural system have the smallest amount of water, when because of tourism consumption is the largest. According to data from hydrogeological investigations, today from karst aquifers in Adriatic catchment have been exploited in total around 9 m^3/s or 2,5% of total water resources in karst areas. Certain water reserves are still out of usage, especially in karst part of Black Sea catchment. Far larger quantity of dynamic reserves in karst areas have been used for production of electricity, but those are retained high water waves in storage basins. Nevertheless still large water quantity freely out flow towards Sava river or Adriatic sea, and those reserves present potential, which can be efficiently used in the future development of the country [8].

The large problem in water resources management in karst areas is the special distribution of water bodies on the distance of nearly 1000 km from Piran bay on north to Prevlaka peninsula on south. It is lack that water resources are distributed in such a way that in present time can cover water consumption of particular regions. So Istria has its own water resources, Croatian Littoral their, than very rich with water Lika region, which cover water consumption of tourist developed islands Rab and Pag, than Ravni Kotari, catchment of Cetina river, and in south part of Adriatic region rich with water Neretva river valley and Dubrovnik area with strong karst springs (Ombla). Part of Black sea catchment which depends to karst areas of Dinarides is also rich with water, and springs of rivers Kupa, Dobra, Mrežnica, Korana and Una have the status of strategic reserves for future development of the country [3]. Croatia has important water resources on some islands as Cres, Krk, Hvar, Korčula, Vis and some others, but these are mainly aquifers of limited possibilities [5], and more and more islands their water supply connect for continental resources.

Basic characteristics of surface flows in karst areas are relatively short flows extended out flow range of torrent type. Numerous short rivers in karst fields are the largest part of year completely without of water, but with frequent floods during rainy seasons. Floods of karst fields have very important function in retaining water mass in high parts of karst catchments, but in the same time bring a large problems for the agriculture of local inhabitants. Hydrotechnic engineers have seen the solutions in artificial fast drainage of karst fields by hydrotechnical tunnels, but such fastening of the natural drainage have had the influence on the prolongation of dry periods, and in such way all negative effects of drying the area, especially in coastal areas. Storage basins built for the electricity production can have a positive influence on out flow effects from karst catchments, because the technically acceptable lost of water from storage basins can increase the basic out flow on karst springs during dry periods.

Obviously is that water resources require the large attention if somebody wants to put water in the order of important element of development of karst areas and whole country. Formula is generally simple, but difficult to be realized. It is necessary to have good water resources management based on knowledge about natural systems according to principles of sustainable development.

4 Water Resources Protection

Water resources protection is today very complex question, because there are less and less quality potable water in the world just thanks to contaminations, which permanently damage available water resources. Croatia is one from rare European countries, which has high quality water resources, foremost because of relative inferiority of development in past period, and also because of the early including in the processes of protection its water resources [10]. However, it is not the equally good situation with water resources protection. Richer by water north part of state in Pannonian basin has much more problems with the keeping water quality from naturally higher vulnerable karst areas.

In **Pannonian basin** is located city of Zagreb and numerous other towns and industrial centres, Sava and Drava rivers and developed agriculture production, which usually create large problems to open porous aquifers. In the north part of Croatia is located the largest consumer of potable water, and this is the city of Zagreb with the consumption of around 5 m^3/s, which because of the inappropriate protection practically ''runs'' after its potable water reserves, and numerous water extraction sites inside the city are abandoned because of the disrupted quality. Downstream from Zagreb increase the problem of natural content of iron in water, but this is relatively easy soluble problem. Needs to stress that there is no to much problems with nitrates in Sava river catchment, which is the general problem of groundwater all over the world because of negative influence of agriculture production. Pumping stations have protection zones and protection measures, however the space becomes more and more expensive and protection measures increasingly overpass in domain of technical interventions in function of protection. In the catchment of Drava river is more expressed the problem of groundwater pollution with nitrates, especially in upstream Varaždin aquifer. The reason is for sure developed agriculture production, and also storage basins, which retained the natural out flow from the area of aquifer. Regardless of existing protection zones for the pumping sites, nitrate problem is possible to be solved by rational usage of fertilizers and pesticides in combination with technical interventions, which can enable faster out flow of surface water from entire area. Recently is very actual research of deeper parts of aquifer, which has the smaller pollution influence from the surface. Water capturing from deeper parts of aquifers should insure future supply with healthy potable water in Pannonian area. New research methods enable better defining of intrinsic aquifers water dynamics, time of water exchange in aquifers and many other parameters, which enable more efficient use and protection of aquifers.

The large problem of water protection in Pannonian basin is the water quality of Sava and Drava rivers, which directly influence on groundwater reserves, by quantity and quality. Needs to emphasize that the quality of water in two rivers are generally improved, because there are less dirty industries in catchments, and the treatment of waste water are the obligation of all states in catchments. Consequently, the regional negative impact is generally decreased, but there are more and more local pollutions because of growing use of area.

In **karst area of Dinarides** the situation with water resources is completely different from Pnnonian basin, because it is naturally higher vulnerable water resource because of the fast groundwater flows and openness of karst aquifers towards fast influences from the surface [7]. Karst aquifers are in the exceptional state because of the lower development of the mountainous area of Dinarides. If we speak about vulnerability than needs to mention large towns in coastal area, which influences expand on some places deep inland. First measures and protection zones of karst aquifers have been established already by the end of 1970s, what was of exceptional importance for the preservation of water quality. Although the knowledge of researchers about thirty years ago were on lower level than present, have been made the documents, which have focused the attention of space users on the value of karst potable water springs and need of rational use of space in zones of high risk. Those documents have been meritorious for the avoiding mistakes, which already were done in developed European countries. Special attention from very beginning of the investigations, designing and construction of infrastructural objects was given to the locating of high risk objects according to the water protection scheme. It is for sure that with karst aquifers needs to be very careful, because uncontrolled interventions and impropriate protection can essentially change natural relation rock – water, what can have incalculable consequences for the whole environment.

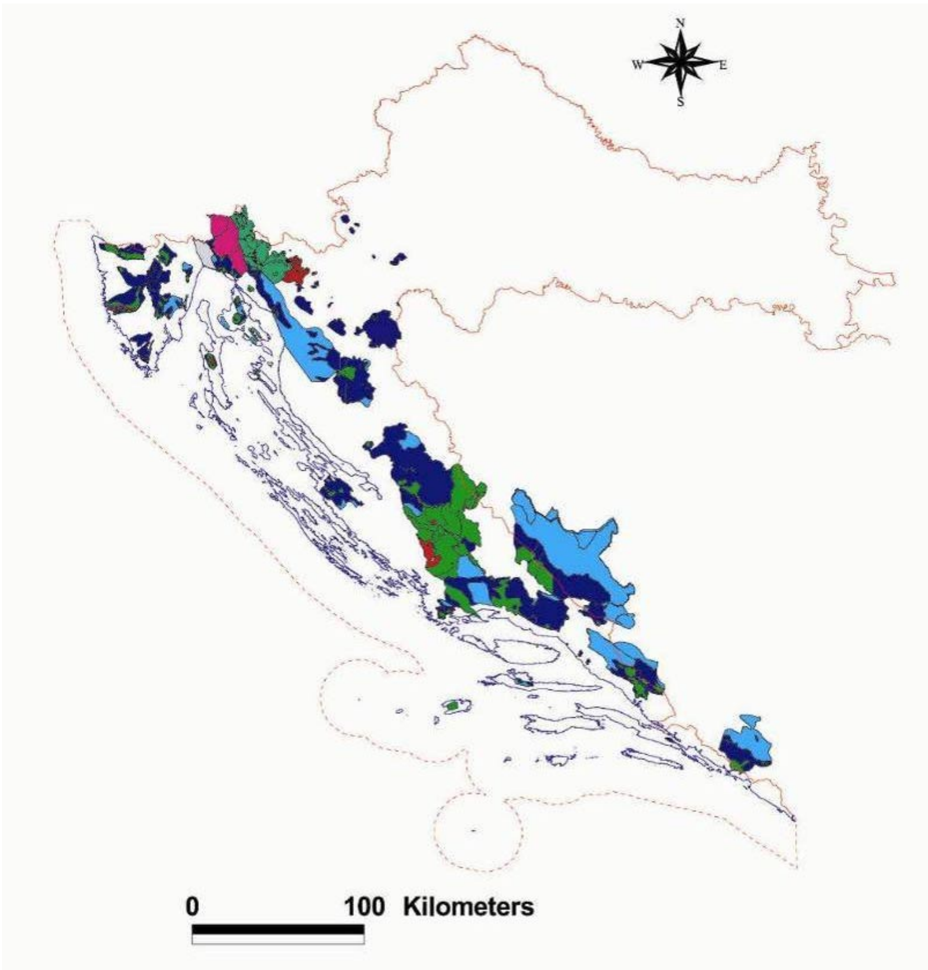

Figure 8. Protection zones of karst potable water springs in Croatia.

New Book of Regulations in Croatia about water resources protection has professionally and organizationally solved earlier problems of different approaches and direct the reconstruction of existing protection zones according to the experiences in Croatia and other European countries. The basic idea of new Book of Regulations is active approach to the protection with as small as possible protection zones and as much as possible efficient protection measures. Methodologically it means the defining of natural vulnerability level, hazard and risk analyses by using GIS for every single catchments.

Criteria for the determining of protection zones from the hydrogeological aspects are surely the most significant part of investigations [7]. Substantially this is the identification of natural drainage systems, geometry and dynamical functioning of aquifers. All past criteria were directed towards protection against bacteriological pollutions – maximal 50 days transport. Unfortunately, bacteriological pollutions are not any more the largest problem. Today the actual problems are hydrocarbons, nitrates and other chemical contaminants. It would be ideal against chemical contaminants to protect whole karst catchments, but in this case karst area of Dinarides would be transformed in protection areas of springs, what practically would disable any urban, infrastructural and industrial development of south Croatia. Solutions are definition of differently active part of karst aquifers and selective protection. The basic parameters are groundwater flow velocities, length of transport, type of infiltration, functioning of unsaturated zones and other natural parameters, which can diminished natural vulnerability of karst aquifers. In Croatia separates the 4 zones of different level of protection. From Fig. 8 is visible that under the protection is nearly half of karst areas in Croatia, and that problems are not so simple, because the large parts of karst catchments extend in neighbouring countries, and protection of water resources is the object of common research and management.

5 Conclusion

Republic of Croatia has water resources, which with their quantity and quality present the significant natural resource for current and future development of the state. Pnnonian area is rich with surface and underground water, but this in the same time the area of largest load, because all big towns lie and develop on their own groundwater resources. This is the area of the largest consumption of potable water, and also the area of smallest influences of seasonal changes on the natural aquifers, so water quantities because of deep aquifers are not questionable. Groundwater level decrease during summer dry seasons can more influence on the technical solutions for pumping stations than on natural lack of water. Water quality is the largest problem of Pnnonian basin, because the part of aquifer along Drava river is already burdened by nitrates, but neither aquifers along Sava river are not out of this influence. Solutions lie in the water exploitations from deep parts of porous aquifers, where hydraulic characteristics are slightly weaker, but expected water quality are much better. Research of deep parts of aquifers look for knowledge about new research methods, which enable better definition of intrinsic aquifers dynamic. For this moment situation with water in north Croatia is relatively good, but trends direct on the caution, especially in the zones of big cities and towns. Water in north Croatia is surely resource, which is indispensable for the development of this part of state. Commercialization of water in this area can be connected just for smaller users for water bottling, and that is possible from deep part of aquifers, where there are enough high quality water.

Water resources in karst areas are completely different story. Some catchments are still completely unused, and some of them just partly. Other great advantage of karst area is vicinity of the coast and more economic possibilities of water transport. Nevertheless, in karst areas problems with water are not so simple because of natural characteristics of the aquifers – combination of low water retaining abilities in karst underground and high level of natural vulnerability. Solutions of those problems are the background of the consideration about usage of karst water. Quantities can be solved by accumulating high water waves, and efficient protection only by good knowledge about natural systems and the system of exploitation, which will not essentially disturb natural conditions. Karst water resources surely present comparative advantage in future development of the country, because quantities overpass the needs of own development, and today's state of water quality and regulated protection measures in a way are guarantee for the maintenance of such conditions in future. Croatian scientists have started with the preparatory project for the commercialisation of ''free'' part of water reserves in Croatia for our offer of water to the Mediterranean market, where many countries have more and more problems with potable water. Part of the project is related on the water supply of tourist very attractive our islands, which also have big problems in the insurance of sufficient quantity of potable water. Where does lie solutions? Foremost in the definition of the ''free'' natural capacity on different karst springs and other water sources along the coast and in multipurpose planning of water use from existing storages built for the electricity production, and in planning of construction of new storage basins, what can essentially increase the existing available reserves of potable water.

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SUSTAINABLE WATER RESOURCES MANAGEMENT IN LITHUANIAN INDUSTRIAL COMPANIES

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Water resources management has become an important operational and environmental issue in Lithuania. The rinsing costs of dependable water supplies and wastewater disposal have increased the economic incentive for implementing technologies that are more environment-friendly, and can ensure efficient use of natural resources. Wastewater reuse potential for Lithuanian industries was determined and overviewed of the types of industries that could benefit from wastewater reclamation and reuse was made. The Integrated Water Resources Management model *IWRM* is designed for water resources management in the industrial companies and supposes possibilities for process integration and wastewater reclamation technologies according mathematically formulated efficient water consumption criteria.

1. Introduction

The demand for water resources is increasing every day in the world [1]. In the past water was a cheap and abundant resource, the wastewater could be discharged in surface water or to the sewer system without excessive costs and restrictions. However, the rising costs of dependable water supplies and wastewater disposal have increased the economic incentive for implementing technologies that are more environment-friendly, and can ensure efficient use of natural resources [2]. The key European Directive 61/96 "Integrated Pollution Prevention and Control" *(IPPC)* now is going to be implemented in all European countries. The implementation of the Directive is going to be determinant to sustain and encourage water reuse and recycling application. The purpose of the Directive is to achieve integrated prevention and control of pollution arising from a large number of activities listed in its Annex I, leading to a high level of protection of the environment as a whole [3]. The Best Available Techniques (BAT) will be defined for several industrial processes with the objective to eliminate or reduce emissions. As far as the process industries are concerned, it is likely that some of the BATs will implement water reclamation or closed-loop options for industrial water usage. Implementation of IPPC is going to be determinant to sustainable and encouraging water reuse and recycling application in Lithuania as well. The increase of water resources consumption efficiency is understood as the decrease of water amount, which is used on the released production (GDP), at the same time not decreasing the quantity of released production and

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warranting the environmental requirements [4]. The appropriate wastewater treatment and recycling is the only way to break the negative impact of human activities on the environment as well [5].

After analysis of several industrial branches basic water consumption indicators in different industrial companies of the country are compared with foreign countries practice. For example, water consumption in different companies of yarn industry (Figure 1) is much more higher compared to water consumption using Best Available Techniques (BAT).

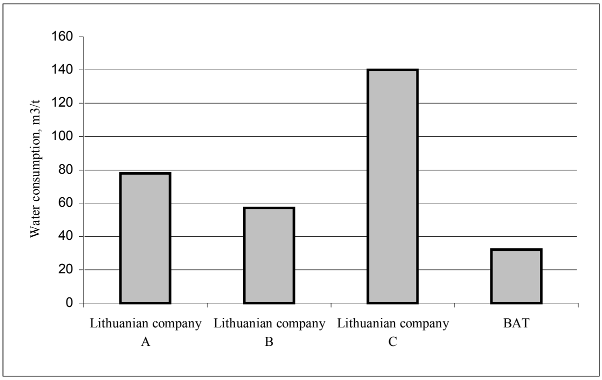

Figure 1. Water consumption in yarn producing companies.

Increase of costs for water consumption and wastewater treatment (Figure 2), made Lithuanian companies looking for new ways of economic effectiveness. Compared to companies and enterprises of developed European countries, the tendencies for water consumption and problems with effective use of wastewater are common for most of industries in the country (textile, pulp and paper, metal processing, food, chemistry, electronics, etc.).

Lithuania, as all the other countries of previous soviet block, inherited economy with very ineffective use of water and other different natural resources. Lithuanian economy consumes several times more of natural resources to produce one unit of GDP than former EU15 average. This is not so long ago, when Lithuanian enterprises were achieving the necessary minimal pollution level by diluting waste water at the end of the pipe. This was the only way to escape huge fines from environmental authorities. Today this is no longer rational, and also makes huge economical damage against the interests of the company [6]. On the other hand, the advanced waste water treatment is costly, and there is a great need in Lithuanian enterprises to start recycling the waste water and starting different types of systems for the water reuse. In Lithuanian strategy for sustainable development the attention is paid to raising the ecological effectiveness of production and services. Actually, there is a lack of clear strategies and models for saving water resources in the country, and this problem raises new challenges for Lithuanian science. With regulation getting more stringent, the increase of water consumption efficiency is a relevant problem today not only in Lithuania but also in EU and other countries of the world.

Various methodologies of systematic evaluation and minimization of water resources consumption were found in literature for different industrial branches. Process integration represents an important branch of process engineering. It refers to the system-oriented, thermodynamics-based, integrated approaches to the analysis, synthesis and retrofit of process plant. The main goals of process integration (PI) are to integrate the use of materials and to minimize the generation of wastes. A recent development in pinch technology that deals with pollution prevention, resource recovery, and waste reduction is mass-exchange integration [7]. One of them, “Water pinch” analysis is a technology providing a systematic approach for minimizing the use of fresh water and the discharging of effluent water without losing sight of the costs [8]. It is a strategic tool for water management in industry. The fundamental theoretical formulations for the application of the pinch concept to wastewater problems were amongst others pioneered by El-Halwagi and co-workers, Linnhoff, Smith and co-workers, Alva-Argáez at al. [9, 10, 11]. The design methodologies and approaches cover a variety of techniques ranging from the graphical based water pinch analyses, the source-sink graphical methodology to mathematical optimization based approaches.

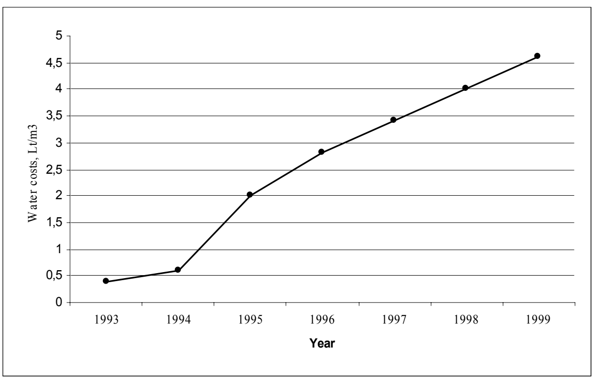

Figure 2. Costs for water supply and wastewater sewerage in Lithuania (1993-1999).

These methodologies all have a range of benefits and drawbacks but the major issue encountered is the expertise required for the practicing engineer to apply these techniques successfully [12].

Nowadays membrane technologies are identified and recognized as a most sustainable and cost effective treatment for water regeneration and reuse of the industrial wastewaters. Membrane filtration has emerged as a reliable and applicable technology in the treatment of various industrial process effluent streams. They are compact and modular in addition to their high selectivity (that can provide substance concentrations as low as parts per billion) and low energy consumption. Therefore, membrane units can relatively easily be implemented on existing production sites [13]. Furthermore, modern membranes present high resistance to heat, to acid and alkaline conditions, to a number of the other aggressive chemicals and of micro-organisms. The membrane filtration can imply savings in water resources, chemicals and production time, and also can give large savings on energy [14, 16].

2 Methodology

The research work of water resources saving in various Lithuanian industrial companies were performed consequently in several stages. In the beginning of the research the effectiveness of water consumption in different Lithuanian companies was analyzed and compared with good practice examples from developed countries in EU and worldwide. Water saving potential in process industry companies was determined. Detailed analysis of "Water Pinch" method and experiment of process integration in Textile Company was performed. The IWRM model methodology was applied in the company for estimation of economical benefits according the efficient water resources consumption criteria.

2.1. *The criteria of efficient water resources consumption*

Expenditure of water resources. The main criterion for efficient water use W_W is based on necessity of minimizing water consumption in companies:

$$W_W \to \min . \tag{1}$$

At the same time it is important to keep high productivity rate and also meeting the environmental requirements of EU standards:

$$N = const ; \tag{2}$$

$$Q \geq Q_{\min} . \tag{3}$$

In the process industry expenditure of water resources for unit of product E_W is the main criteria (indicator) of efficient water consumption:

$$E_W = N . \tag{4}$$

This criterion has to be followed by every enterprise, which uses water in its' technological processes and seeks to minimize water consumption:

$$E_W \to \min . \tag{5}$$

Minimizing of water costs. This criterion can be followed in every enterprise's calculations of water resources and wastewater treatment expenditures, regardless type of industry or technological process used in the company:

$$K = \sum tW_W + rW_{WW} + W_{other} . \tag{6}$$

In this case the objective to be achieved is the decrease of costs of water resources consumption, under conditions (2) and (3):

$$K \to \min . \tag{7}$$

3 Results and discussions

Analysis of preventive methods for water resources saving and wastewater minimization and advanced wastewater regeneration technologies encouraged to create a constitutional model for integrated water resources management in industrial company. The Integrated Water Resources Management (IWRM) model enables to analyze process water system in a static domain, given by a certain time frame, and in a dynamic domain, where time depending changes can be modeled. The step-by-step procedure and the consistent relationships between the input-output diagram types allow straightforward set-up execution of the water saving project.

The Static analysis reveals the structure of the system as flows and processes. A system optimization is possible based on water and on costs, which calculates and balances water resources and wastewater in order to point out possible savings. The diagrams are hierarchal structured on several levels of detail allowing an in-depth analysis of complex systems with numerous sub-systems. The Dynamic analysis involve a water analyses technology called “WaterPinch” for analyzing water networks, which provides a systematic approach for minimizing the use of fresh water and the discharging of effluent water without losing sight of the costs. Detailed water network analysis enables to found out the best water recycling solutions.

3.1. *Application of IWRM model*

There are two main areas for applying IWRM model: 1) technological process in appropriate equipment, which uses water resources (a simple object) and 2) technological chain consisting of several technological processes or equipment consuming water (a complex object). Assessment of technological object relations between these parameters is stipulated. This process can be viewed as demonstrated in Figure 3.

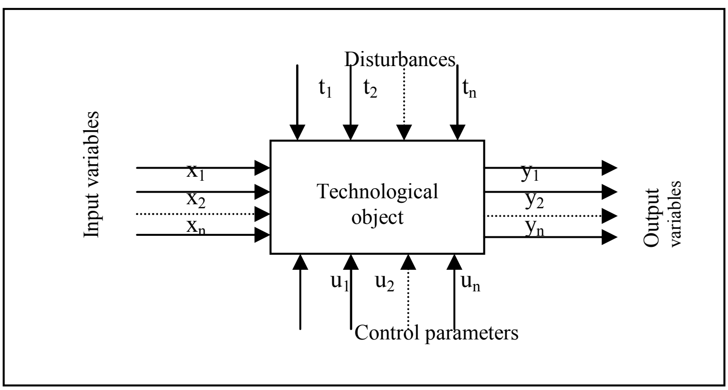

Figure 3. Structural scheme of technological object.

Usually, technological processes are affected by various factors (variables), such as:

- Input variables x1, x2,...xn - which are described by quantitative and qualitative parameters of water consumption. This can be water resources from different sources of water supply – supply agent, own bores, and also the information on the water resources: amount, concentration of separate components, temperature, etc.
- Output variables y_1, y_2,...y_n – these are waste water flows from different technological processes and pollution concentration as well as temperature. These values determine the process mode and describe the state of a technological process.
- Disturbances t_1, t_2,...t_n – effects regarding the changes of water quality, resources limits, changes of legislative requirements.
- Control parameters u_1, u_2,...u_n – changing regimes of technological processes and the compensation of existing interferences.

3.2. *Principle of IWRM model operation*

The IWRM model operation is based on *the optimal solution approach* [4]. The optimum control is a feedback strategy using a combination of the costs of control and system costs as an objective function, and using the system model as a linear constraint. An objective function is understood as water resources usage rates per production unit E_w or minimization of wastewater treatment costs *K*.

The IWRM model is employed for optimisation of the objective function with regard to quality and environmental requirements (Figure 4).

Thus generated effluents contain a wide range of contaminants, such as salts, dyes, surfactants, oil and grease, oxidizing and reducing agents. In environmental terms, these contaminants mean suspended solids, COD, BOD, as well as high pH and very strong color. Cotton represents approximately half of all textiles worldwide, and nearly all cotton today is dyed by reactive dyes [15, 17].

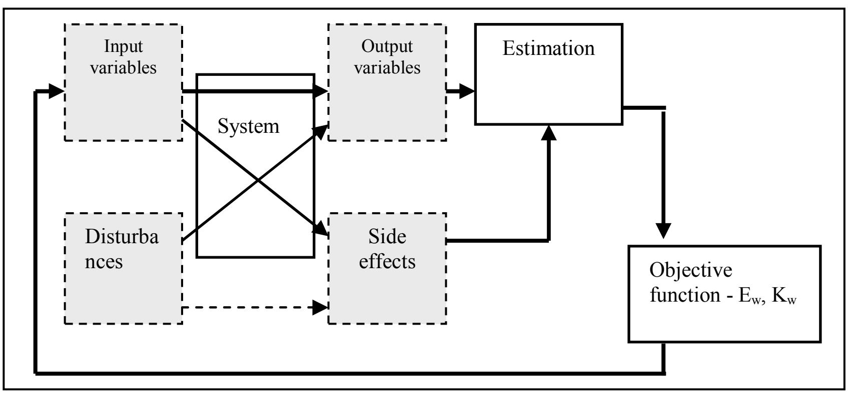

Figure 4. Principal operational scheme of IWRM model.

Washing and rinsing are two of the most common operations in reactive dyeing of cotton and optimization of washing efficiency and can save significant amounts of water and energy. It is common that the rinse has water consumption above 200 l/kg of textile or more than 60% of the total water consumption in the whole refinement process.

Unfixed dyestuffs and auxiliaries must be removed from the goods in order to get high quality products and excellent fastness. Washing subsequent to dyeing is mostly done in a conventional way, which means that the washing process starts at low temperature in order to remove dyestuff and to prevent staining of the white ground. This washing process is time consuming and requires a lot of water.

This model makes it possible to keep the system in balance foreseeing the preventive measures for waste minimisation. When applying the model in a selected enterprise, all possible ways of water should be systematically assessed, i.e.:

- Implementation of the direct water recycle.
- Water collection and reuse in technological processes.
- Application of regenerative technologies for wastewater treatment.

3.3. *The application of IWRM model in industrial companies*

The application of theory to practice, the *IWRM* model (Figure 5) for water resources saving and wastewater minimization in different industrial companies was applied. The main of water resources saving experiments using IWRM model were performed in textile companies. Why the textile companies have been chosen for the experiments? The textile industry wastewater is a significant pollution source containing high concentrations of inorganic and organic chemicals and is highly colored from the residual dyestuffs.

The goods are usually washed too long and too intensively and wastewater drained directly into the waste water treatment plant without any recycling or cleaning in order to get the best rubbing and wash fastness. Applying the IWRM model the following steps were used:

- identification of the machine groups with the largest yearly water consumption;
- evaluation of direct water reuse solutions;
- selection of relevant membranes able to work in the process water from rinsing after cotton dyeing;
- estimation of the reduction in polluting substances in the reclaimed process water after membrane filtration;
- determination the applicability of this permeate for reuse as rinsing water in the dyehouse;
- evaluation economic efficiency of water reclamation by membrane filtration and reuse in processes.

Carrying out case studies, it became clear that *the IWRM* model is applicable in various type of water using production system, especially in large water amounts consuming production systems. For example, using IWRM model in testified textile company was achieved 55% fresh water savings, and correctly applied membrane filtration enable to create closed water loop for textile rinsing process. Integration of “WaterPinch” and membrane filtration technologies ensure process optimization, can provide financial savings, conserve natural resources and help to meet present and future environmental legislation requirement.

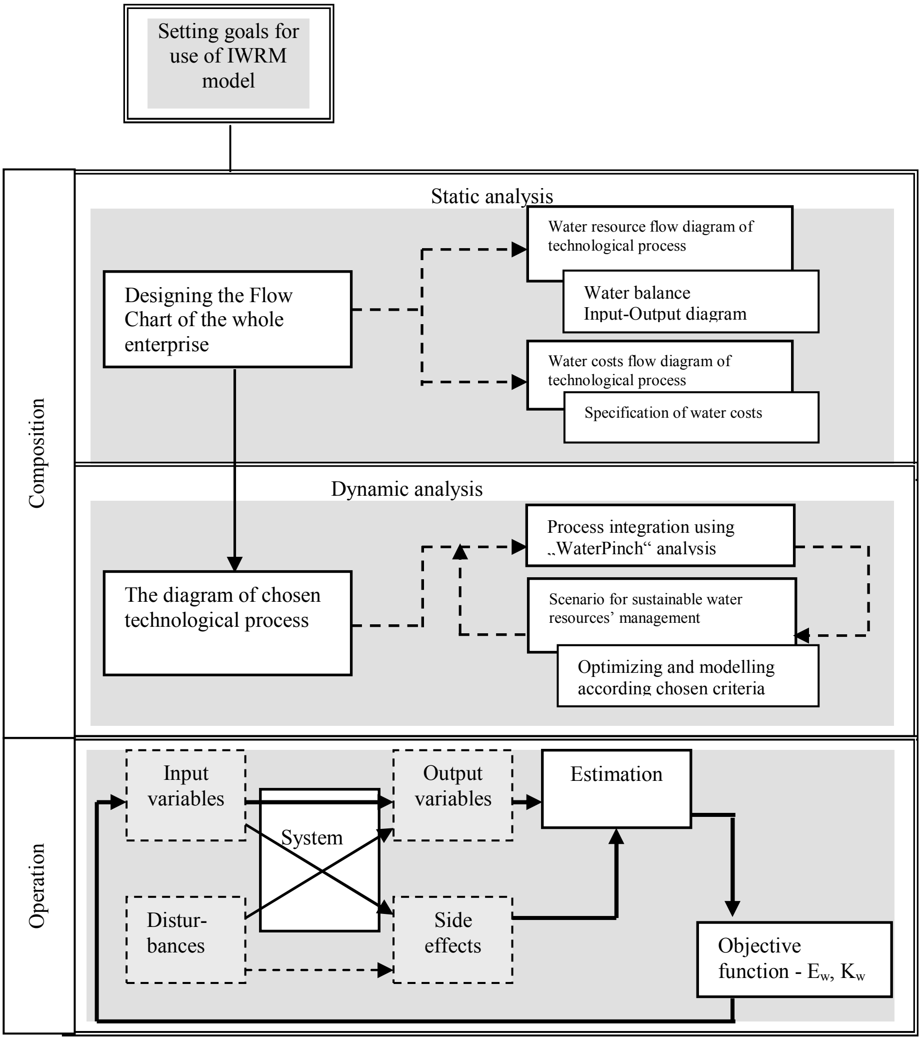

Figure 5. The structure of a model for Integrated Water Resources Management (IWRM) in industry.

4 Conclusions

After analyzing the world practice in wastewater reclamation and reuse possibilities, after calculating various pollution prevention, cleaner production and environmental management projects, implemented in Lithuanian companies, following conclusion were made: there is a huge potential for water reuse, water recycling and closed water cycles in most of companies of different industrial branches. The biggest opportunities for water consumption and wastewater minimization have textile, pulp and paper, chemical, food and metal processing and power generation industries. Comparing to water usage known in foreign practice, many Lithuanian companies exceed water consumption several times, in some cases more than ten times.

The comparative analysis of water resources in industry showed, that the main criteria for effective water use is an input of water resources used for producing a unit of the production (m^3/t, pcs., m). Comparing these criteria between industrial enterprises of developed countries followed by BAT recommendations, Lithuanian enterprises use 3-5 (some cases 10) times more water for production unit, especially in textile, pulp and paper, metal processing, chemistry and food industries.

Applying the IWRM for preserving water resources and minimizing waste water (without the decrease of production amount) results into saving water resources and producing less waste water in the range of 52-62 % depending on the type of industry and type of enterprise. The effect is achieved by creating systems of water reuse, closed water cycles, by integrating methods of process analysis together with technologies of waste regeneration.

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DECENTRALIZED WASTEWATER TREATMENT TECHNOLOGY: A PROMISE FOR THE FUTURE

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Centralized system of collection and treatment of liquid wastes has been in vogue for more than a century now. While this concept has brought general improvement in the hygiene and sanitary situations in the urban areas, the system as such is costly and poses high demand on fresh water used for flushing the sewers. Decentralized wastewater systems offer sustainable alternatives to the centralized systems. These systems make best use of the available technologies and generally involve low maintenance requirements, and a process for reuse and/or dispersing the treated effluent nearby through the soil and ground water recharge. This paper gives an overview of the technologies that have been successfully applied and potentially used, and advocates that decentralized systems containing these technologies should be produced using modern industrial methods and delivered in a user friendly state. Further, these should be serviced and maintained by a team of skilled people.

1 Introduction

Man made his early settlements near the rivers so that he could have convenient supply of fresh water and fish and easy means of communication. Community wastewaters of all sorts slowly found their way into natural water courses. While the population levels were small and wastes consisted of small quantities of natural substances, withdrawal of water and/or the discharge of wastes had no significant impact on river ecology. However, with the rise in population, increased urbanization and industrialization - large quantities of wastes of increasing complexities found their way into natural watercourses resulting in unhealthy conditions and disease outbreaks, necessitating discharge of community wastes further away from human habitation. Thus centralized system of management of community wastewater was evolved. In this system sewage from the city is collected, centrally treated and the effluent is disposed of in natural watercourses. These systems are designed and managed to cater to specified quality criteria of the receiving body of water. Over the years, these sewage disposal systems have to be successively upgraded, to keep up to speed with the stringent discharge requirements in natural water courses. While these systems have brought about significant improvement in public health situation, they impose large demand on water needed to transport (and prevent settlement of) sewage solids in the pipe network, and require approximately A$10,000 per household in initial cost and A$500 in annual rate per household [1].

The fact that large number of people in the developing world still do not have access to adequate sanitation is a clear indication that the centralized approach to sanitation is not adapted to the socio-economic conditions prevailing in most countries of Africa, Asia and Latin America. Furthermore, the (extra) water used for flushing the centralized systems dilutes the potentially useful substances and nutrients (e.g. phosphorous) in wastewaters to an extent that these cannot be cost effectively recovered or utilized. Centralized system, therefore, does not also correspond to basic criteria of sustainability since it is estimated that the global phosphorous reserve will last only some other 50-100 years if they continue to be depleted at the present rate [2].

However, the good news is that on September 8, 2000 in the fall session of the UN General assembly 191 Member States reaffirmed their commitment to half, by the year 2015, the proportion of the world's people who do not have access to safe drinking water and ensure integration of the principles of sustainable development into country policies and programs and reverse loss of environmental resources (www.un.org/millenniumgoals). When assessing the chances to meet these targets, one must take into account the large amount of money needed to build the infrastructure needed. According to rough estimates released by the World Bank, up to 180 billion of US$ need to be spent every year to bring the 'rest of the world' to the standards in the industrialized countries during the past 150 years. While, these cost estimates are based on the water and wastewater management practices of the past, if we were to come up with novel technological concepts that are comparably effective but costs much less, the financial burden would come down lower than that estimated by the World Bank.

Around 80% of the total costs of the overall water supply and wastewater treatment are attributed to installation, maintenance and repairs of the conveyance/reticulation system alone. Thus if alternate wastewater management systems could be developed so that extensive sewer networks would not be needed any more, it would be easier to realize the UN development goals in the developing country environment, plus advance a sustainable alternative to the current centralized sanitation system in the developed countries too.

2 Alternative Approaches to Wastewater Management

2.1. *Onsite Treatment*

Another approach to wastewater management is the Onsite treatment. This involves treating and dispersing the wastewater on the site of the building lot. Typically these systems are privately owned and operated and are often the most practical and cost-effective solution for wastewater treatment and disposal in small rural and remote communities, where municipally/centrally managed systems may be costly to build and maintain. Septic tank is most commonly used. This is basically a holding tank where natural bacterial action decomposes human waste products into environmentally acceptable components - the major end-components being water, mixed with some other components that are not readily consumed by the bacterial action, gases, and undigested solids. The treated effluent percolates in soil and recharges ground water in the local area. Approximately 18 million housing units or 25% of all housing units in US manage their wastewaters using onsite treatment and disposal systems [3]. It has been estimated that only 32% of the total land area in US has soil suitable for conventional onsite systems. While many of the onsite treatment systems have been designed to take full advantage of the receiving soil's ability to treat/assimilate effluent constituents, a review of literature reveals isolated instances of installation of the dispersal systems on lands that were not suitable for such systems. Such practices coupled with lack of knowledge at the individual household level for efficient operation and maintenance of these systems, have resulted in contamination of wells or nutrient enrichment of lakes especially in the areas where there was pressure for development. As such, onsite systems have often been plagued by poor public acceptance and considered temporary method(s) for dealing with wastewater until the real sewer is constructed, for no fault of the onsite technology.

A review of literature suggests that onsite systems now include a number of alternatives that surpass the conventional septic tank and drain field systems in their ability to treat wastewaters. Alternative onsite processes include: dual septic tanks, intermittent sand filters, recirculating filters, peat filters, extended aeration package plants, fixed film package plants, denitrification unit preceded by a package aerobic treatment unit, small wetland systems, and/or disinfection chambers. Leach fields, soakage trenches, spray irrigation systems, evapo-transpiration beds, and evapo-transpiration seepage systems have been normally used alongside the treatment units as soakage systems. Other alternatives include a "mound" system where a suitable soil is placed above the unsuitable soil, followed by installation of a pragmatic onsite system [4]. The issue of the EPA 2002 'Onsite Wastewater Treatment Systems Manual', as a supplement to the 1980 design manual, provides a useful resource in supporting the use of modern technology and methods for installing and maintaining these pre-treatment and land application systems. Similar protocols have been incorporated following a six-year period of joint standards development by Australia and New Zealand. The result has been the introduction of a non-prescriptive approach to design in the AS/NZS 1547:2000 for 'Onsite Domestic Wastewater Management'.

It has been reported that where onsite systems are managed by a professional, systems do not fail. Periodic inspection results in any maintenance that is needed being done in a timely fashion, and also rids the owner of worry that if the system is no longer working they have to spend a large sum of money to replace them. While it is generally desired that owners of the onsite systems have a management contract, there has not been a rigorous procedure for assuring that maintenance of systems is being done. Often times after a couple of years, owners find that their systems are working and they drop the maintenance contract. Successful programs of the future should be based upon performance concepts and should incorporate management programs that provide regular monitoring and maintenance for these systems. Several State universities in US have set up field based training centers for raising the educational and practical skills of practitioners. Education and training of all practicing professionals followed by certification and licensing programs in future will enhance the output from the onsite systems.

2.2. *Decentralized Treatment*

An intermediate system, based on the decentralized or small scale concept, is receiving attention because of perceived numerous advantages over the other two systems. This system serves a cluster of buildings grouped in a specified area. Typically a decentralized system involves treatment of low maintenance requirements, a collection system and a process for dispersing treated effluent usually through the soil and ground water recharge. Decentralized systems may incorporate onsite systems as a part of a managed cluster. The wastewater from each dwelling or business flows into its own interceptor (septic tank). From this tank, the effluent is able to travel through small diameter, therefore less expensive, collection pipes (could even be pressure sewers served by grinder pumps at individual buildings). These pipes are buried at a shallower depth than full sewers and run relatively short distances to smaller, less maintenance-intensive treatment and disposal units. These units often use soil absorption fields or effluent recycling rather than discharging the treated wastewater into surface waters. Decentralized systems can well be used to take some of the load off centralized wastewater treatment plants by 'scalping' wastewater off the sewer mains in the vicinity of parks or other green spaces to recycle nutrients and the water load. It may be noted that since the final receiving agency in this case is the soil, treated effluent criteria do not have to be as stringent as in the case of centralized systems because the ultimate goal here is to make sure that the effluent does not pose risk to ground water reserve after getting through the soil.

The concept of decentralized system fills the gap between onsite systems and the conventional centralized system. This approach results in: (a) less environmental disturbances as the smaller collection pipes are installed at shallower depths that can be more flexibly routed; (b) encourages the flows at any point to remain small, implying less environmental damage from any mishap; (c) allows different management strategies to be employed in various parts of the service area, responding in the most financially efficient and environmentally responsible manner to each subset of circumstances; (d) encourages cost effective recovery and reuse of potentially useful substances and nutrients in wastewaters and (e) encourages industrial wastewater generators to implement their own in situ treatment methods specific to their wastewater characteristics and reuse opportunities; (f) allows wastewater management to be broken down to the neighbourhood level and to serve disaggregates of large urban areas, resulting in community scale and low cost treatment facilities ranging from a simple septic tank to modular and compact waste treatment plant, waste stabilization pond, constructed wetlands, algal ponds, maturation ponds, disinfection units followed by subsoil waste disposal systems, etc. In the decentralized system - design strategy revolves around to determine how close to the source of generation it is practical to address treatment and disposal. This is guided by how the wastewater could be used in a beneficial manner. Other considerations may include topography, soil conditions, development densities, and type of land use.

3 Decentralized Systems in Urban Areas and Developed Country Environment

Decentralized wastewater systems have been working satisfactorily around many parts of the world for up to a population level of 50,000. In 1997 the town of Pegram having a population of 2000 people, several businesses, bank, and restaurants faced the problem of failing septic tanks and drain fields that were used for sewage treatment and disposal. The town leaders initially looked into installing a centralized system to collect and treat wastewaters and dispose it of in Harpeth River located 10 miles away west of Nashville, Tennessee. However, not only the costs of sewerage were prohibitive but the plan did not meet community's approval that was actively working to protect the local environment and did not want the treated effluent discharged into the river. Decentralized system using new watertight septic tanks at each home and business and a watertight collection system running to a sand-gravel filter treatment, and effluent disposal by subsurface drip irrigation in a nearby farm pasture was the final choice made and has been working effectively [5]. Other typical example is the mobile Alabama where central wastewater authority is actively identifying locations where wastewater could be treated in decentralized fashion using packed bed filter and then soaked in soil via subsurface drip irrigation [6].

4 Decentralized Systems in Semi-Urban Areas and Developed Country Environment

Semi-urban areas in developing countries are characterized by a mixture of land uses where settlements are generally inhabited by communities of different economic status. Many industries locate at the edge of the city because the land is cheap and is not subjected to stringent developmental controls. The infrastructural facilities that are provided are often inadequate. Majority of settlements in peri-urban areas, particularly those inhabited by poorer communities, do not have access to adequate water supply and sanitation facilities often because these communities have 'poor political contacts' and hence given low priority in allocation of resources. In many cases, wastewater is discharged locally into open ground or vacant plots, creating foul–smelling stagnant pools. This leads to widespread pollution of surface and ground water and deterioration in environmental health conditions. At the same time, increasing competition for limited water resources results in farming communities in these areas to use untreated wastewater for irrigation and aquaculture. There are potentially serious health consequences for both those who work, often bare footed, in agriculture and aquaculture and also those who consume produce which is irrigated with untreated wastewaters. In these situations, decentralized systems can offer pragmatic solution as these can be designed not only to treat wastewater locally in low cost units but also encourage reuse of effluents to increase local agricultural productivity resulting in increased revenue for local producers who then can be motivated to pay for the improved services.

Nhapi [7] demonstrated how the decentralized treatment concept can be beneficially used in Zimbabwe conditions to treat and dispose combined or separated wastewater streams. The less concentrated wastewaters are treated by natural treatment methods like algal ponds or constructed wetlands with harvesting of protein biomass, and the concentrated wastewaters are treated in anaerobic ponds followed by disinfection in maturation ponds and then reused for local agriculture or pasture irrigation or aquaculture. Sumare City in the State of Sao Paolo, Brazil, has successfully used decentralized systems comprising of upward flow anaerobic filters, baffled reactors, and upward flow anaerobic sludge blanket reactors to remove up to 90% of organic load from its domestic wastewaters [8]. In Khulna, Bangladesh, waste stabilization ponds have been integrated with pisci-culture (fish farming), where it is a source of income generation for the local people. Community based groups are responsible for operating and maintaining these ponds and the local city council is responsible for the management side. Benefits of the use of decentralized technology have been demonstrated through researches carried out in Malaysia too but these systems have yet to catch up in the country because people are still not concerned about the shortage of water resource as Malaysia is still considered as a water-rich country [9].

5 Public Acceptance of Decentralized Wastewater Treatment

In New Zealand (NZ) all natural and physical resources are managed through a single piece of legislation, Resource Management Act (RMA), 1991. The Act stresses an integrated approach for all the resources with the goal of sustainable management. One of the underlying principles of the RMA is that its decision making process is best left to those who are directly affected by the results of those decisions. RMA therefore expects the local community to tell their local councils what they value about their environment, so that the councils can look after them in the manner they like. Approximately 14% of the NZ population consists of indigenous (Maori) people. Maori regard water as a treasure left by ancestors for sustaining use of their descendants. This concept fits well with the intent of RMA that promotes sustainable use and management of natural resources. Accordingly, RMA requires resource managers to explicitly take into account Maori views, culture and traditions on how to manage this important resource.

Maori believe that natural waters have spiritual life force and that's why the water in rivers, lakes, ponds, sea, harbour, estuary etc, can support living species. It is believed that the spiritual life force can be easily harmed by artificial components, such as chemicals. Maori also believe that addition of chemical(s) would disturb the balance in natural waters, and the water would then be not able to support living species and this would adversely affect the food chain. According to Maori culture and values all direct discharges of wastewaters, whether treated or untreated, should be prohibited into waterways. Therefore the practice of discharging effluents into rivers, seas, estuaries, etc is not acceptable to Maori community, particularly where the water is used for traditional food gathering, e.g. fishing, etc. On the other hand, Maori believe that the earth is the provider of food and shelter. Maori view earth as mother earth, which is saviour. Maori believe that mother earth can accept all our sins and has tremendous power of (ritualistically) purifying wastewaters. Accordingly, wastewaters, if disposed in water, must be routed through land, that has tremendous power of treating wastewaters. Many of the local bodies in NZ have responded positively to Maori cultural beliefs to discharge effluent either into water following extensive development of wetland sewage treatment systems, or disposal directly into soil via seepage.

6 Decentralized Systems Offer Flexibility

So, how does a community decide which management approach is right for its wastewater treatment? When town leaders face having to plan for wastewater treatment, the first choice usually is to build a centralized collection and treatment facility. Given the obvious strengths and potential of the decentralized approach, why is it not more often implemented by planners and wastewater management agencies? This resistance against decentralized wastewater management systems has many roots: Institutions involved in the wastewater sector prefer conventional systems for which they have well established design standards and operating procedures. Furthermore by selecting familiar solutions they feel much more comfortable implementing their interventions, given the fact that many regulations and policies hinder innovative new approaches. Also, there is a general perception on the part of stakeholders (planners, engineers, and users) that non-conventional (decentralized) systems offer sub-quality service, which clearly shows that there is a lack of knowledge for these technologies.

Cost has always been a primary consideration in deciding among wastewater treatment options. Costs include the money needed to install the system and the annual cost to operate and maintain it. During the 1970s, 1980s and early 1990s, the federal or state governments provided direct funding to help build wastewater treatment facilities. This money more often made its way to larger municipalities, and many smaller towns never received any of these funds. Consequently, wastewater management problems were never resolved in many small communities. Today, direct funding to communities is nearly nonexistent. Communities now must depend on low or no interest source of funding for installing, repairing, and upgrading wastewater systems. It is argued that while urban and suburban areas with high population densities (more than three to four dwellings per acre) would probably be better served by centralized wastewater collection and treatment, this technology is definitely not the right answer for small towns and rural and sub-urban areas because: population may be too spread out to make centralized system cost effective; also this option may not necessarily befit their socio-cultural needs, and/or not encourage the flexibility of reuse of effluents locally to increase agricultural productivity resulting in increased revenue for the community [10].

7 What is Needed to Make Decentralized Technology Competitive?

It is obvious that a holistic approach must be taken to offer a sustainable and financially affordable method of wastewater management. There is never a universal solution to such problems, but every local situation has to be analyzed, including the financial bearing capacity of the community, the education status of the people, climatic conditions, traditions and even religious concerns. Education and continuing information is needed to bring the local population to the level needed to evaluate alternatives and make proper decisions.

The main challenge for planners and practitioners not only rests to create awareness for the community to take informed decision on the appropriate decentralized technology focusing on improvements in the local environment, but also in making available these technologies in modular and user friendly state. Further, these should be manufactured using latest tools, plants and materials under controlled conditions. When mass produced, the cost for manufacturing such compact plants can be kept at a relatively low level to offer economy. Educational materials directed to homeowners should explain proper wastewater disposal and maintenance practices, as well as provide information about the consequences of system failures. Increased awareness about decentralized systems ought to help reduce the number of failing systems and the eventual negative effects on ground and surface water.

8 System Must Be Managed

Management is the key to keeping decentralized treatment systems functioning properly. Management can encompass planning, design, installation, operation, maintenance, and monitoring these systems. This involves change of focus of activities, whereby traditional central agencies take on a different role, focusing on the need for capacity strengthening to develop new skills to respond to the needs and demands of the communities, thereby providing technical assistance and coordinating the activities of different stakeholder groups involved in decentralized wastewater management. Improving skills levels of practitioners via effective training and information transfer has a significant contribution to make to achieve the sustainable decentralized wastewater management program. It also requires that these institutions develop capacities for monitoring and regulation, and put in place effective systems for enforcing appropriate policies since regular inspection and maintenance form the basis of any management program.

9 Conclusion

Sustainability considers economic, environmental and social factors in development. For wastewater treatment, small and decentralized systems provide a better means for achieving sustainability, compared with centralized collection and treatment system. In remote and rural areas as also in new urban developments decentralized technology needs to be practiced to achieve improved sustainability than is currently practiced. Simplified low cost, modular and compact decentralized plants should be developed using controlled manufacturing technology to cut costs. Further these systems should be managed by a team of well qualified and trained persons. Continued effort in research, development and demonstration at community level is still required for acceptance of this technology.

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SUSTAINABLE DEVELOPMENT OF WATER MANAGEMENT IN CROATIA

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Issues related to the concept of sustainability are analyzed in the paper. Water guidelines issued by the European Union, actually setting the framework for all water related activities, are described. They are the action plan, instructions and foundations of every reasonable policy of sustainable development. The water management concept for catchement areas can be regarded as a novel approach to water management. It is emphasized that water is not a commercial commodity but rather a heritage that has to be preserved so that civil engineers, and water engineers in particular, bear a lot of responsible development in this area. Human beings as well as wildlife and ecosystems need water for survival. Because of climate variability and change, population growth and development, water scarcity and poor water quality are threatening many regions. In most instances, scarcity as well as pollution is linked directly to poor water management and missing water infrastructure. Improved water management requires not only good engineering, but also science-based analysis, efficient institutions and co-operation among stakeholders.

1 Introduction

The concept of sustainable development of water resources management considers environmental issues, economic problems and socio-economical implications equally important. This concept demands that economic actions should not be taken at the cost of future generations´ freedom to develop (WCED, 1987). Sustainable development approach to water management is a concept which emphasizes the need to treat long-term future in a manner similar to the treatment of the present. Sustainable water management is planned and managed with the aim of achieving present and future goals set by the society at large, without disturbing ecological, environmental and hydrological integrity. How can water management be sustainable when the future cannot be forecast with any level of certainty? We have no positive knowledge about any future impact caused by our present decisions. Nevertheless, we still have to consider the situation in which the future generations will be if we develop current water management plans, projects and policies. Sustainability is closely related to various levels of risk and future uncertainty. Future development forecasts might be incorrect, thus the need for periodical revisions. The awareness of the fact that some water management goals will change over time forces us to consider the flexibility of present planned system. Since sustainability is a combination of different economic, environmental, ecological, social and physical goals, water management must definitely include a multi-disciplinary decision-making process.

The main goals of sustainability in water management can be summarized as follows:

1. On the long-term basis, the quality and quantity of the aquatic resource as an essential element of life for humans and nature must be guaranteed.
2. The usage of renewable water resources should not surpass their ability to regenerate themselves.
3. The input of substances in the environment should not surpass the self-purification capacity of waters.
4. The operating costs of water resource management solutions must be oriented on the population's standard of living.

All existing approaches for putting the concept of sustainability into operation serve more as orientation aids and cannot be implemented as instruments for planning and assessing concrete measures. The main cause for this is that sustainability describes an ethical principle which is to guide all future economic activities, rather than a definite condition. Rules for sustainability can be seen as guard rails. Under these conditions it becomes obvious that the realization of sustainability can only be achieved by going through a process of weighting alternatives, that is, by comparing different plans of action using the same norms.

The complexity of cause and effect in the realm of water resource management, as well as the demands for transparent and comprehensible decisions in the context of discussions on the inauguration of sustainability place demands for new ways to prepare and realize planning processes in the field of water resource management.

1.1. *Definition and Significance of Sustainable Management*

In 1987, the World Commission on Environment and Development (the Brundtland Commission), [1], observed that "Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the future. Similarly, it could be said that sustainable water management is management that meets current needs without compromising the ability of future generations to meet their own needs - both for water supplies and for a healthy aquatic environment. You can delete our sample text and replace it with the text of your own contribution to the proceedings. However we recommend that you keep an initial version of this file for reference.

For example, sustainable water management requires approaching the range of water problems and the variety of types of water bodies (from freshwaters to oceans) in an integrated way. Recognizing that water management cuts across all uses of water - from water for drinking and irrigation to aquatic environments that support fishing, tourism and recreation - planning and interventions must be cross-sectoral. Planning and management must be predicated on meeting both human needs and the requirements of the aquatic environment for sustainable supplies of water in adequate quantities and of acceptable quality. Increasing attention must be placed on demand management as well as supply-side alternatives [2]. Two main options are available:

1. Improving institutional and financial arrangements that make water services more tuned to demand, that stimulate conservation and improve cost recovery.
2. Improving integrated planning of water use, and allowing water resources to be valued properly at the macro- and micro-economic levels, notably by removing open and hidden subsidies and regulations that distort their market price, prevent competition and promote wastage.

Both of these options call for actions that are challenging to governments and that will demand further elaboration and adjustment to local conditions. They are likely to affect a country's national policies on economics and resource management. They may also shape the way in which it sets priorities, and organizes local and national decision making, its civil service, budget, project administration and its educational and research system. Your manuscript will not be reduced or enlarged when filmed so please ensure that indices and other small pieces of text are legible.

2 International Conferences Focusing on SDWRM

Several International Conferences have been held in the past ten or more years focusing on Sustainable development of water management - SDWRM. Here the outcomes of the four most influential ones are summarised.

Dublin 1992: International Conference on Water and Environment. In January 1992 International Conference on Water and Environment Issues for the 21st Century, was held in Dublin, Ireland. It served as the preparatory event for the Rio Conference with respect to water issues. The conference reports sets out recommendations for action at the local, national and international levels, based on four guiding principles. Current thinking on the crucial issues in water resources is heavily influenced by the Dublin Principles, which are [3]:

- Fresh water is a finite, vulnerable and essential resource, which should be managed in an integrated manner.
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- Women play a central role in the provision, management and safeguarding of water.
- Water has an economic value and should be recognized as an economic good, taking into account affordability and equity criteria.

UN Conference of Environment and Development - Agenda 21 . The Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests were adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, 3 to 14 June 1992, [4], Agenda 21 is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment. The Commission on Sustainable Development (CSD) was created in December 1992 to ensure effective follow-up of UNCED, to monitor and report on implementation of the agreements at the local, national, regional and international levels. The full implementation of Agenda 21, the Programme for Further Implementation of Agenda 21 and the Commitments to the Rio principles, were strongly reaffirmed at the World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa from August 26 to September 4 2002.

The Hague 2000: Second World Water Forum & Ministerial Conference. On 17-22 March 2000, the Second World Water Forum was held in The Hague, Netherlands [6]. In almost hundred sessions, more than 5700 participants from all over the world discussed the urgency of the water crisis and debated the steps required to ensure the sufficiency of clean water for all of us in the future. Privatisation of water–or more precisely, the issue of public/private partnerships–received a lot of attention during the forum. Water is a basic human right was another hot topic. The key issues raised in the Second World Water Forum [7] are:

1. *Privatisation:* To achieve water security, water must be everybody‘s business but on the other hand the government monopoly in water management should not be replaced by a private monopoly.
2. *Changing the full cost for water services:* Users should in fact be charged the full cost of the services–with appropriate subsidies made available to the poor.
3. *Right to access:* Water is not only considered essential for human health, it is also desperately needed by millions of poor women and men in rural areas for productive reasons: to grow the family food or generate income. Almost 90 percent of our water resources are used for agriculture. Right of land and use of water are key determinates for people‘s potential to break down the poverty trap.
4. *Participation:* Water can empower people and women in particular, through a participatory process of water management. Participation implies sharing of power, democratic participation of citizens in elaborating or implementing water policies and projects, and in managing water resources.

Bonn 2001: International Conference on Freshwater. In December 2001, International Conference on Freshwater took place in Bonn, focusing on water as a key to sustainable development. The Bonn Conference was the major preparatory event in the water field towards the Johannesburg Summit of 2002. The Conference brought together government delegates from 118 countries, including 46 ministers, representatives from 47 international organizations and delegates of 73 organizations from major groups and the civil society.

The conference reviewed the role of water in sustainable development, took stock of progress in the implementation of Agenda 21 and identified how its implementation can be improved [8]. It is built on many previous efforts and conferences, which have defined the challenges, development principles and policies related to water and sustainable development. There is often a gap between making such policies and putting them into practice. So the conference focused on practical ideas. The Bonn Keys are listed below [9]:

1. The first key is to meet the water security needs of the poor.
2. Decentralization is key. The local level is where national policy meets community needs.
3. The key to better water outreach is new partnerships.
4. The key to long-term harmony with nature and neighbour is cooperative arrangements at the water basin level, including across waters that touch many shores. For this reason IWRM is needed to bring all water users to the information sharing and decision making tables.
5. The essential keys are stronger, better performing governance arrangements.

3 EU Water Framework Directive

For most people in the European Union access to clean water in quite abundant quantities is taken for granted. Most people do not realise however, that all many human activities put a burden on water quality and quantity. All polluted water, whether polluted by households, industry or agriculture, returns back, one way or another, to the environment and may cause damage to human health or the environment. The Water Framework Directive - WFD of the European Commission was adopted and finally entered into force in December 2000 [10, 11]. As opposed to the water protection of the 1990s, the area covered by this Directive extends to all aquatic systems, surface waters (rivers and lakes), groundwater and coastal waters. Land eco-systems depending on groundwater are also included in the protection of the quantity of groundwater. Therefore water resources should be managed across national boundaries, choosing a co-ordinated approach within the river catchment areas.

The main target of this Directive is for the "good status" of all waters in the Community by 2015 whereby there is a differentiation between the ecological and chemical status of water. The basic thinking behind the term "good ecological status" is that water can be used by humans as long as the ecological function of the water body is not significantly impaired. The ecological function is defined by requirements for the different types of water by the EU. It still has not been specified how to define good ecological quality and how to carry out the assessment of water. The chemical water status is to be determined by environmental quality standards for hazardous substances.

Another key point of the Directive is the combination of an emission related approach with discharge related measures to reduce pollution under the basic obligation of cost recovery.

The WFD suggests four main fields of action:

1. Development of principles for integrated planning and management of waters.
2. Implementation of regulations concerning the quantitative protection of water resources.
3. Establishing instruments to control groundwater pollution by non-point sources.
4. Implementing instruments to control groundwater pollution by point sources.

4 Sustainable Water Management

Sustainable water management means putting all of the pieces together [12]. Social, environmental and technical aspects must be considered. Issues of concern include: providing the forums; reshaping planning processes; coordinating land and water resources management; recognizing water source and water quality linkages; establishing protocols for integrated watershed management; addressing institutional challenges; protecting and restoring natural systems; reformulating existing projects; capturing society's views; articulating risk; educating and communicating; uniting technology and public policy; forming partnerships; and emphasizing preventive measures. The challenge is to guide water management decision-making into flexible, holistic, and environmentally sound directions [13, 14, 15]. Water resources professionals must be prepared to offer credible guidance to those who need it, at the right time, and in a comprehensible form.

4.1. *Constraints to be Dealt with*

Sustainable water management is conceptually sound. It should certainly be the goal, and if at all possible, the practice. Conceptualization, however, is easier to accomplish than implementation. The more comprehensive the management approach, the more tortuous the path [16, 17, 18]. There are a host of barriers that must be overcome if we are to successfully engage in truly integrated watershed development and management. Roadblocks include:

1. The manageability of holistic approaches in a practical sense.
2. Agency, interest group, and political boundaries (boundaries of authority and space).
3. Government, agency, and professional biases and traditions.
4. The lack of effective forums for assembling and retaining stakeholders.
5. The narrow focus, lack of implementation capability, poor public involvement, and limited coordination attributes of many water resources planning and management processes.
6. The separation of land and water management, water quantity and water quality management, surface water and groundwater management, and other direct linkage actions.
7. Poor coordination and/or collaboration among state and local water-related agencies. States tend to view water management from a macro scale perspective, while local governments focus on issues such as storm drainage and wastewater treatment.
8. The gaps in scientific knowledge related to ecosystem functions.
9. Limited ability to value environmental systems on monetary or other scales.
10. The public's perception of risk as opposed to the reality of risk associated with water management options; Suspicion regarding the formation of partnerships.
11. Poor communications links among planners, managers, stakeholders and others.

5 The Role of Science and Experts in Developing Sustainable Water Management

Information transfer and education are partners. Informing the public, decision-making bodies, and others begins with their education as children. The better informed on water-related issues our citizens are, the more likely they are to demand quality decisions by their elected representatives. Decisions are based on information [19]. Furthermore, the better informed the decision maker, the more likely he/she is to make good choices. And college courses and curricula dealing with water and environmental management should be expanded to include their total dimensions - legal, social, political, technical, and environmental.

In addition to the solution of the institutional status and the provision of a stable funding, to be able to fulfil the social role of water management means that it is necessary to ensure the inclusion of adequate professional/scientific foundation, which consists of the three segments:

- Development of data base and establishment of water management information system.
- Research, studies and project documentation.
- Staff training for water management purposes.

Water management is a very expensive long-term activity, which necessitates quality research and studies in the first implementation stage of water management plans. A multi-disciplinary approach is a significant requirement of contemporary efforts in the field of water management [20]. The speed of changes is much greater than the length of a person's active life, which implies the need for permanent on-the-job education, so that necessary knowledge can be gained and optimum solutions produced.

The implementation of the policy of sustainable use of water resources, water protection and protection from adverse effects of water opens up a number of problems which cannot be solved without significant activities of researchers in the field of hydraulic engineering, or specialists in various other scientific disciplines, with the common goal of achieving research objectives such as:

1. Improvement of measures and development of technologies to produce best possible effects in water use and protection.
2. Improvement of flood and drought management measures.
3. Improvement and development of wastewater treatment and reuse technologies.
4. Water redistribution and transport within river basins for optimum water use, under conditions of preservation of natural ecosystems and other space values.
5. Development of agriculture under water saving conditions and reduction of surface waters, groundwater and soil contamination.
6. Rational groundwater use.
7. Improvement of water resource management system at different levels.

8. Rational, sustainable use of water resources and avoidance of potential conflicts of interests and competences over water resources.
9. Rehabilitation of endangered environment, and thus also water and ecosystems.

There are significant differences among countries with regards to the achieved levels of research, knowledge and technologies which should support and facilitate optimum solution to sustainable use of water resources. Positive results of international cooperation at the level of river basins, regions or international organizations are evident, and are also catalysts for new international projects [20]. Each segment of planning and water management presents a challenge to researchers due to the complexity of phenomena which stem from interaction between natural processes and human activity in the water sector. The following research is particularly significant for integrated water management:

1. Application of modern technologies and facilities in the processes of measurement, data collection and processing, planning, management and decision-making. The main objective of research is the modelling of processes in the simplest, most accessible manner possible.
2. Improvement of forecasting models, in particular with regards to the integration of stochastic phenomena and processes. Knowledge and assessment of potential risks in the water sector are relevant for decision-making.
3. Integration of research of surface water and groundwater quality, particularly from the standpoint of human impact.
4. Improvement of methods and procedures of control, monitoring of processes and environmental impact assessment of water management activities.
5. Determination of environmental protection indicators, and thus also of water quality and aquatic ecosystem, i.e. limit values of sustainable water use.
6. Exploration of river processes, erosion, deposit flow and sedimentation in reservoirs, and deposit management.
7. Improvement of river basin management methods, starting from physical and socio-economic limitations.

It can be concluded that without research, i.e. formed scientific and expert teams, technical equipment, developed information systems, application of modern technologies and continuous investment and funding of scientific potentials and scientific institutions, the basic goals of sustainable water resource development policy cannot be achieved.

6 Conclusion

Integrated water management is the paradigm for the 21st century. The true spatial, environmental and institutional, dimensions of problems must be recognized, and they must be dealt with accordingly. The status of water management is the result of numerous factors active during a longer time period. The future requires taking numerous concrete steps in measure systems, which should ensure improvement of institutional and financial status of water management. Integrated water resource management sets new objectives, principles and standards for policy making and the necessary environment for its implementation. Global and international conventions, especially the EU Water

Framework Directive, represent relevant documents for water management activities. Introduction of a new policy requires significant changes in the current practice of planning and water management, institutional organization, legislation, funding, etc. There is a necessity of strengthening expert and scientific foundations of water management and integration of institutions in charge of data collection, analysis, planning, design and water management development and operation. Based on the basic goals of holistic approach to water resource management, relevant preconditions for its implementation are defined, with particular emphasis on the roles of scientific research, strengthening of the information communication technology - ICT support, comprehensive application of new technologies and international cooperation on the activities of implementation of integrated water management policy. Water management issues are presently solved by application of a systematic approach. The distribution of water resources is spatially and temporally very uneven; the available water is increasingly a limiting factor in socio-economic development, and thus a relevant factor in politics as well. Freshwater demands are constantly increasing. Water should, therefore, be continuously evaluated and preserved by appropriate management. Joint actions at the local, national and global levels can ensure sustainable development, with the imperative of water resource management in a sustainable manner.

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QUANTITY AND QUALITY CHANGES OF WATER RESOURCES ON THE LANDSLIDES OF 'DANUBE TYPE'

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Territory of the northern slopes of Fruska Gora has characterised with unstable slopes with intensively moving after intensive rainy periods or under anthropogenic influence. Terrain encircles urban, industrial, and rural surfaces. It is in the zone of gradual protection of the National Park 'Fruska Gora'. Technical methods in protection of natural resources could not been directly recommended. Because of the complexes hydrogeological processes and mutual relation of natural and anthropogenic factors of risk, it is very hard to value even if their positive influence on stability of slopes. In that case, the stationary observations of quantity and quality regime had been set on the paleolandslide 'Sremski Karlovci', which is situated on the watershed of Strazilovo stream. Measuring has been doing monthly in 16 spots (springs and artesian wells). For now, it has been determined seasonal periodic with little amplitudes of releasing water. Water was not respond with standards for water supplying because of high contents of ammonia, iron, manganese, and boron. These components are characteristic for waters from turbidite and pliocenic aquifers. On the observed spots in the bottom of the landslides, concentrations are higher than relating concentrations over the edge. In some shallow wells, even hard metals have shown, which indicators of pollution from surface are. We had foreseen that the experiments should last three years. This is the first year of monitoring.

1 Introduction

Researching terrain encircles surface of 65 km^2 in the watershed of Esikovac stream on the paleolandslides Sremski Karlovci. Upper part of the spring is in the zone of Eco-park Fruska Gora, and lower part of Esikovac stream flows through Sremski Karlovci and inflow into branch of the river Danube. This part also belongs to the Eco Park Fruska Gora as the native wetland.

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2 Methods and materials

In the aim of saving the ambient whole of Sremski Karlovci, reconstruction and restorations of existing public wells and springs are necessary. During the last year, monitoring of quantity and quality regime of spring water on the paleolandslide Sremski Karlovci have been organized, as the base for the project of reconstruction, which should be done. The existing documentation were used for researching: interpreter for the basic geology map, paper of Novi Sad, in proportion of 1:100000 [1], engineer-geology researching needs for the general regulatory plan of community Sremski Karlovci, as result of bacteriology and chemistry frequent control of spring waters corrections. Experiment has been set as part of M.Sc. Thesis from the student of environment in The Faculty of Agriculture in Novi Sad.

Locations of springs and common wells had chosen according followed criteria:

- Regional distribution.
- Vertical distribution.
- Vertical "artesian" wells (different depth).

Monitoring encircles 16 locations. In the meantime, one public well has aborted. In continue, monitoring encircle 15 spots. Well capacity and temperature have being measured one time in month, and short analysis 4 times per year. Laboratory researches of water sampler include the basic physical parameters: color, odor, taste, stirrness and hardness. Chemical analysis includes essences anions and cations, microelements, hard metals, hazard substances of anthropogenic source, so that is totally 44 parameters. Obtained results, until now, are not sufficient for applying statistical methods on it.

3 Researching results

Formed accumulations of groundwater in the watershed of Esikovac stream are under dominated influence of geologic basis and engineer- geologic processes alongside right Danube slopes. According to interpreter for the basic geology card [1], watershed of Esikovac stream were built up of sedimentary rocks from Triassic, Cretaceous, Miocene and Pliocene time period. Aeolian sedimentary loess from quaternary time period is widespread on the surface of terrain and over covers all older rocks with depth in range of 1,00-20,00 m.

3.1. *Triassic*

It spreads over the wide area outside watershed of Esikovac stream. It shows with dolomites and sill filled limestone, which are tectonic disturbed. On the terrain, it detects in the form of horst.

3.2. *Upper cretaceous*

It has been showing in facials of sandstones, conglomerates, and shales with cyclic changing which have been characteristic for flysch. These sediments are widespread over the upper part of watershed of Esikovac stream. There are large series with tectonic deformations and general fall toward northeast and north, relatively to Sremski Karlovci and Danube dislocations.

3.3. *Miocene sediments*

They spread over the lake shallow water facies with coal band. These are showing with conglomerates, sandstones, clays, and shales. Marine Miocene is regional divided on north slopes of Fruska Gora and transgressively lays over the older formations. They reformatted a little bit and fell over north and northeast. In the watershed of Esikovac stream, marine Miocene is present with mudstones and mudstones clays.

3.4. *Pliocene sediments*

Pliocene sediments have detected in the lower part of watershed, relatively alongside Danube dislocation. They are bending over to north and northeast. They are in tectonic contact with older sediments. In vertical profile sandstones clays, coal clays, and coal band have been changing alternatively. Gradually they cross into River Lake and torrential sediments of lower Pleistocene. They have fallen toward regional erosion basis of the river Danube.

3.5. *Quaternary sediments*

They are widespread over the surface of terrain in the watershed. They had detected in sandstone clays and sands in bottom layers, with depth fewer than 30 m. Three loess strata overlay continual and every of them begin with terrigenous gravel and sands in the bottom layer, than goes aquatic loess and continental loess.

Landslides alongside right bank of the river Danube appeared because of the slopes of layers and exchanging of sand-clays sediments. Slopes moving is seasonal and per annual. Sremski Karlovci situate on one big landslide that layers moves in intensive increase from time to time. Sediments caught by sliding are sediments of quaternary period and part of sediments from Pliocene up to decomposition bark. Sliding area overspread under alluvial sediments in riverbed (under 100 m from right bank), and depth is in the range of 5- 40 m. Local landslides expressed after spring snow melting, moreover rainy years or intensive precipitation.

4 Monitoring of quantity and quality regime of water resources

On the terrain of paleolandslide Sremski Karlovci had not been set new observation network of artesian wells and captured springs. Monitoring had organized on 16 existing water screen areas as follow: four captured springs and twelve artesian wells (Figure 1). Captures had been built up in XVIII century (later they were only reconstructed). Water had distributed with pipes toward urban part of Sremski Karlovci. These captures show the beginning of water supplying town. More street artesian wells situated in the lower part of landslide had been born during XX century. Today, there are springs for general water supplying and water supplying network for central water supplying. However, as the integral part of ambient Sremski Karlovci these springs and street artesian wells are still in use and inhabitants take care for them.

4.1. *Spring quality regime*

Monitoring has been doing in equal monthly intervals. Spring flow, water temperature, and air temperature is measured every month. Monitoring planned to last for the 25-30 months, with aim for getting time series, which could be statistically prepared. For the period of 8 months, it was consolidated follow (Figure 1):

- *Spring No.1*. "Mutica" has the changing water capacity and varies from 0.286 l/s up to 0.45l/s, and its outflow is in direct connection with precipitation regime. After intensive gain of precipitations or snow melting, water from this spring gain muddy. Water temperature varies in the range of 12.5ºC up to 16ºC, (water is divide with pipes from water capture to discharge point), because of the influence of temperature regime of air and land.

Figure 1. Regional map of Sremski Karlovci with monitoring locations.

- *Spring No.13*. In Micurinova Street is very close to capture. Its capacity varies from 0.077 l/s up to 0.08 l/s. just in July 2004. It has been measured the capacity of 0.11 l/s. water temperature varies from 15ºC up to 16.8ºC. This capture has one more water divide (location 14) with constant water discharge of 0.016 l/s, so than total water capacity of this captured spring is 0.14 l/s.
- *Spring No.15*. "Doka" is located outside urban area in upper zone of unstable slope. Its capacity varies in the range of 0.03 l/s up to 0.83 l/s, and water temperature in the range of 12ºC up to 16ºC. Variety of the regime is in connection with type of spring in the landslide body (Figure 2).
- *Spring No.16* "Devojacki izvor" situated on the road to Novi Sad, in exit of Sremski Karlovci and discharges on the spot where it had captured with capacity from 0.50 up to 0.55 l/s, and water temperature varies from 13ºC to 14.5ºC.

Figure 2. Spring in the landslide body.

All springs are mostly upward, with low catchments area, shorter staying of infiltrated precipitations in water permeability geologic area. They discharge on contact of impermeable Pliocene or Pleistocene sediments and conglomerates and sandstones from flysch series. Only spring "Doka" represents typical spring in body of landslide [2].

4.2. *Artesian well quality regime*

Monitoring has been doing in equal monthly intervals on 10 locations. There are bore wells with different radius of well construction and depth. Sand layers had captured on depth from 30, 60, and 100 m. Depth of the layers varies from 5 to 10 m. These layers are bended to north and northeast. Sandy layers located on different depth under 60 m are disturbed and located in central or lower parts of paleolandslides "Sremski Karlovci" (locations 5, 6) piezometric level of aquifer is bigger according to layer depth. Well capacity even depended upon construction radius. Discharge regime are with high amplitudes in shallower wells, and constant in wells which are collecting water from undisturbed sandy layers (Pliocene) on depth over 100 m (locations 3, 10). Capacity of artesian wells varies in the range of 0.025 l/s to 0.37 l/s. water temperature of shallower artesian wells varies from 13ºC to 18ºC, and in deep wells from 19ºC to 20.5ºC.

Quantity regime of springs and artesian street wells show on Figure 3.

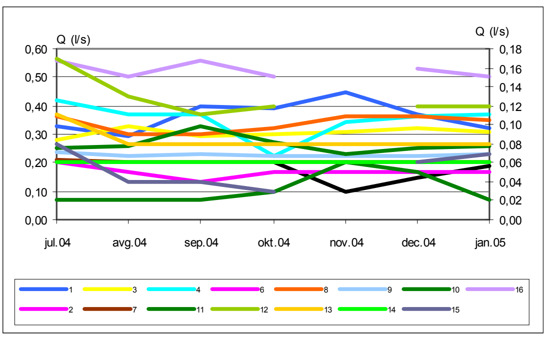

Figure 3. Discharge regime of spring water on the paleolandslide "Sremski Karlovci".

Quality regime of water resources on given locations include, besides frequent controls of chemical water structure for little number of parameters (which could be from anthropogenic factors) complete chemical analysis of 56 parameters that should be doing 4 times per year. According to important anions and cations all waters could be set into group of hydrocarbonated-calcic waters. TDS varies from 0.352 g/l in spring waters, up to 0.964 g/l in waters from depth over 100.00 m. Hydrocarbon contents varies in range of 0.390g/l-0.523 g/l, sulphate contents from 0.011 g/l up to 0.041 g/l and chloride from 0.013 g/l to 0.024 g/l. Dominating cations are calcium (0.076-1.122 g/l), magnesium (0.030-0.080 g/l) and sodium (0.011-0.022 g/l) [3]. All important anions and cations are under MAC (maximum allowed concentration) in drinking water. Other parameters that have also detected in groundwater on the area of Sremski Karlovci are contents of ammonia (0.16-2.30 mg/l), nitrate (0.69-57.66 mg/l) [3]. There are from anthropogenic influence. Increasing use of fertilizers from farms and changes in land cultivating are the main factors of water pollution with nitrates. They stay very long in groundwater that could cause problems in the future. From micro components, it is constantly high value of boron (1.0-2.80 mg/l). His origin could be anthropogenic and geologic. Figure 4 show a correlation between contents of boron and calcium, and it could be seen that the boron is genetically connected with sedimentary rocks from flysch series.

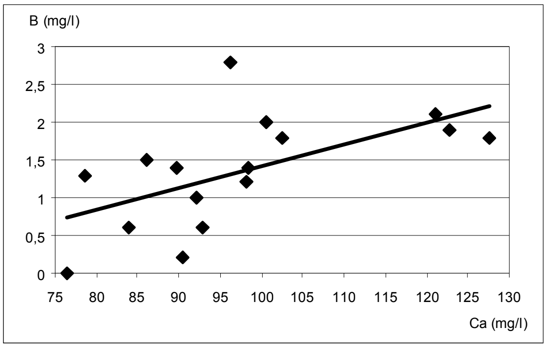

Figure 4. Diagram of dependence boron of calcium contents in groundwater on landslides Sremski Karlovci.

5. Conclusion

In the course of frequent control of spring water quality in Sremski Karlovci, seasonal appearance of nitrogen triads over the MAC from anthropogenic influence had been set. That caused the need of urgent reconstruction of existing captures. The main goal is making the base for project of reconstruction and protection of town ambient whole that lays over the paleolandslide, during the last year monitoring of the quantity and quality regime of spring waters in Sremski Karlovci.

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WATER DESALINATION AND TREATMENT

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MULTI-EFFECT BOILING SYSTEM MEB: AN ENERGY VIEWPOINT

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All desalting systems consume energy, either thermal or mechanical or both. In the search for energy efficient desalting systems, it is clear that the reverse osmosis RO desalting system is more efficient than the widely used multi stage flash MSF desalting system. For seawater in the Gulf area, as an example, the RO consumes about 5 kWh/m^3 of mechanical work, while the MSF desalting units consume about 4 kWh/m^3 pumping energy, beside thermal energy. The thermal energy input to large MSF units is in the range of 250-300 kJ/kg, and is usually in the form of slightly superheated steam extracted from steam turbines at about 2-3 bar. The equivalent work of this thermal energy is in the range of 17 kWh/m^3, [1]. The conventional multi-effect boiling MEB desalting system (simply called MEB here) uses about half of the MSF pumping energy, and almost the same amount of thermal energy used by the MSF, if both have the same gain ratio. However, recent trend of using low temperature MEB, (LTME) allows the use of low temperature (in the range of 70°C) steam as heat source, and consequently of low exergy and low equivalent work. This can bring the LTME consumed equivalent mechanical energy close to that consumed by the efficient RO system. In this paper, the conventional multi-effect desalting system is revisited to show that thermal energy input to low temperature MEB is low, and can bring the equivalent mechanical energy, and thus the consumed fuel energy to low values close to that used by the seawater reverse osmosis SWRO desalting system, mechanical energy, and thus the consumed fuel energy to low values close to that used by the seawater reverse osmosis SWRO desalting system.

1 Introduction

In practice, the efficiency of distillation desalting systems, in term of consumed energy, is usually measured by some terms defined by:

1.1. *Gain Ratio, GR*

The gain ratio is D/S, where D is the distillate output and S is the steam supplied to the desalting system (both have the same units):

$$GR = \frac{D}{S}.$$

This rating method does not account for the steam enthalpy difference across the desalting unit, the supply steam quality (temperature and pressure), or the pumping work.

1.2. *Performance Ratio, PR*

The performance ratio PR is the amount of desalted water produced by condensing 1 kg of steam at average temperature corresponding to 2330 kJ/kg latent heat:

$$PR = \frac{D}{(Q_d/2330)} = \frac{2330}{(Q_d/D)} = \frac{2330\,D}{\Delta h_s\;S_d} = \frac{2330\,GR}{\Delta h_s},$$

where Q_d is the heat supplied to desalting unit and Δh_s is the enthalpy difference of the steam across the unit. When steam is supplied as saturated vapor and leaves as saturated liquid then

$$Q_d = S\,L_s,$$

where L_s is the steam latent heat. Than the PR becomes

$$PR = \frac{2330}{L_s}\frac{D}{S} = \frac{2330}{L_s}\,(GR)\cdot$$

It is more rational to use PR than GR since it counts for the enthalpy drop of the supplied steam, but still does not count for the steam availability or the mechanical work used by the pumps.

1.3. *Specific Heat Consumption, Q_d/D*

The specific heat consumption is the heat energy consumed to produce 1 kg distillate:

$$q_d = \frac{Q_d}{D} = \frac{2330}{PR}.$$

Although the previous three expressions are widely used, they are not really appropriate to evaluate the performance of the desalination system for two reasons:

1. The pumping energy W(pump) is not accounted for, and
2. The quality (or the availability) of the used thermal energy is not considered.

As an example, the condensation of 1 kg of saturated steam at 1 MPa (T_{sat} = 180°C ≅ 453 K) gives 2015.3 kJ/kg heat, while at 40 kPa (T_{sat} = 76°C = 349 K) gives 2319.2 kJ/kg. Counting only by the amounts of thermal energy, one can conclude that 1 kg of steam at 40 kPa gives more condensation heat than that at 1 MPa. However, this is not true when the steam quality (pressure and temperature) is considered. The value of the steam is measured by its ability to produce work. The reversible (maximum) work w_r produced by 1 kg of saturated steam at temperature, T_s, and ambient temperature T_e = 300 K is:

$$w_r = L_s \left(1 - \frac{T_e}{T_s}\right)$$

The term w_r is called the specific exergy or the availability:

1. For 1 MPa, w_r = 2015.3 [1 - (300/453)] = 680.7 kJ/kg.
2. For 40 kPa, w_r = 2318.55[1 - (300/349)] = 325.6 kJ/kg.

This clearly shows that the real value of steam at 1 MPa is almost twice that at 40 kPa.

Other meaningful criteria can be considered in the rating of the desalting systems such as:

1. The specific fuel energy: The amount of fuel energy used to produce the required thermal energy Q_d and mechanical energy W(pump) required to produce 1 kg of distillate.
2. The specific consumed available energy: The available energy W_r of the supplied steam plus the pumping work W(pump) required to produce 1 kg of distillate.
3. The equivalent specific mechanical energy: The work W_d equivalent to the thermal energy and the pumping work W(pump) required to produce 1 of kg distillate.

This paper revisits the multi-effect desalting system through examples from operating units, and presents its main characteristics. The suggested terms used to evaluate the efficiency of thermal desalting systems (specific consumed fuel, specific consumed available energy, and specific equivalent work) are applied to evaluate the real performance of the multi effect desalting system.

2 Conventional Multi Effect Desalting System

The conventional multi effect desalting system, MEB, is the oldest method used to desalt seawater in large quantities. It has many variants such as forward feed, Figure 1, parallel feed Figure 2, mixed feed, and backward feed, Figure 3. In the forward feed, both water

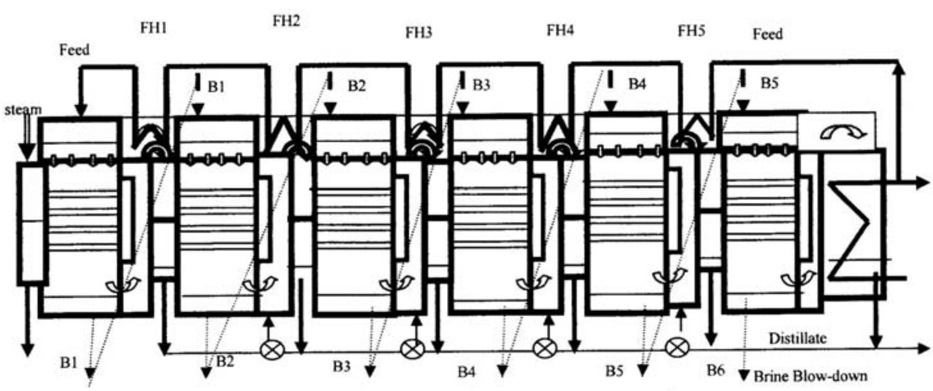

Figure 1: Forward feed multi effect boiling with regenerative feed heaters.

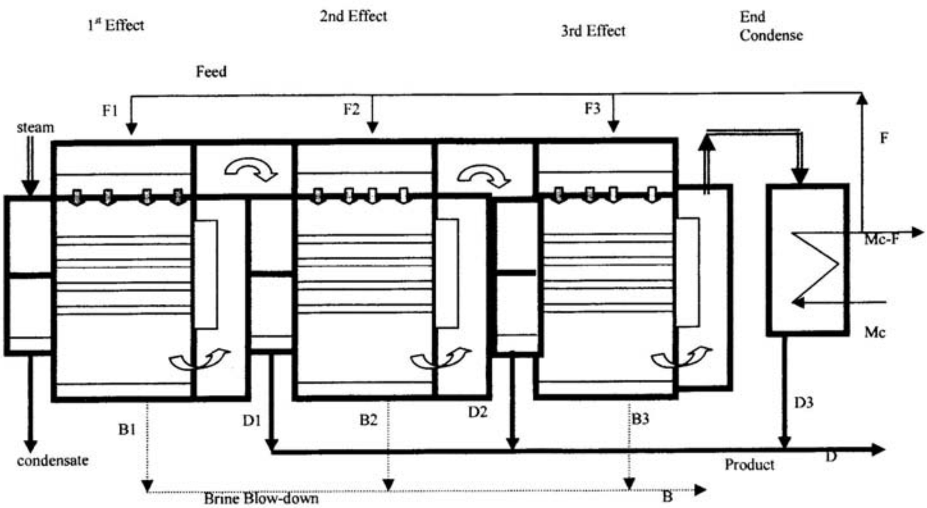

Figure 2. Parallel feed multi effect desalting unit with no pre-feed heaters.

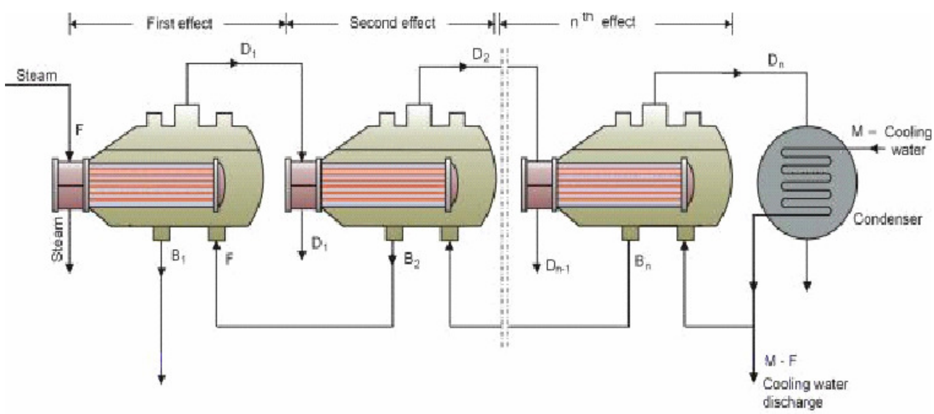

Figure 3. Backward feed multi effect desalting system using submerged tube evaporators.

feed and heating vapor to the evaporators flow in the same direction; and hence the least salinity is at the highest temperature in the first effect. In the backward feed system, where heating vapor and feed flow opposite to each other, is rarely used in desalination since the first effect has the highest temperature and salinity.

Early MEB units used submerged tube evaporators as the ones shown in Figure 3. In these evaporators the heating coils are submerged in pool of boiling seawater; and were known with low heat rates and high scale formation, [2]. Modern MEB units use falling film evaporators (either horizontal as in Figure 4 or vertical as in Figure 5) and feed

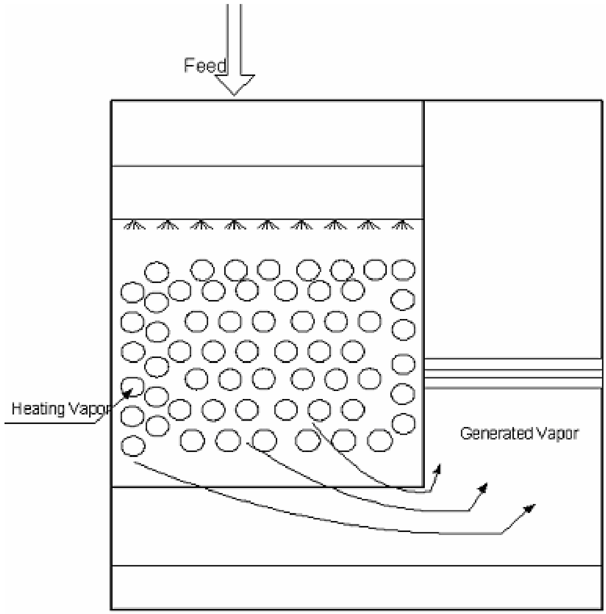

Figure 4. Horizontal falling film tube evaporator.

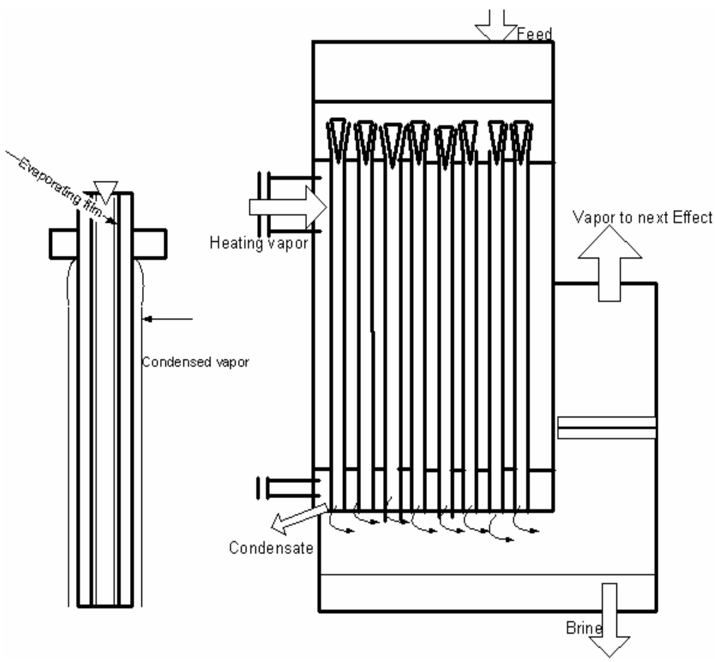

Figure 5. Falling film vertical tube evaporator.

heaters FH between effects as in Figure 1. Parallel feed is used when partial or no feed heaters are used between the effects. The evaporators can be placed horizontally next to each other as in Figure 1, or stacked vertically as in Figure 6, [3]. Falling film evaporators are characterized by their high overall heat transfer coefficients, (the range of 3.5-kW/m^2°C).

In horizontal tube evaporators HTE, the heating vapor flows and condenses inside the horizontal tubes. The feed is sprayed by nozzles or perforated trays and flows as film around the outer surface of the tubes, and evaporated by heat transfer across the tube wall from the condensing vapor, see Figure 7.

In vertical tube evaporators, the feed flows as a film flowing down next to and concentric with the inside surface of the vertical tubes; while heating vapor is condensed on the outer surface of the tubes and its condensate flows down.

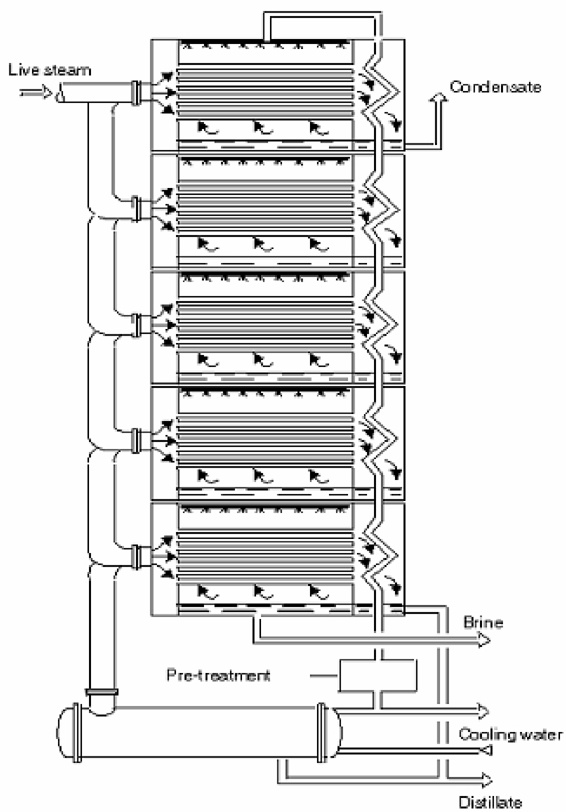

Figure 6. Multi effect desalting system with evaporators stacked vertically [3].

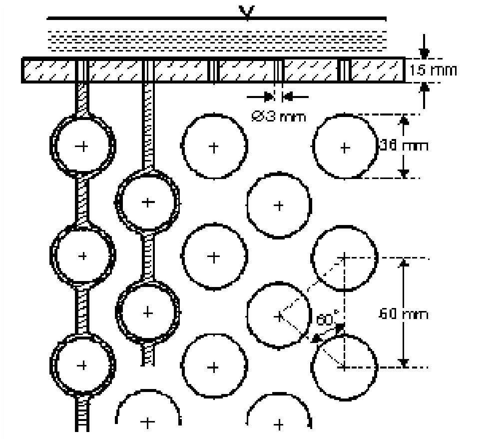

Figure 7. Typical arrangement of a sieve tray over a tube bundle.

2.1. *Simple Analysis of Forward Feed with Feed Heaters*

In forward feed shown in Figure 1, cooling water M_c enters an end condenser at t_c to condense D_n (last effect vapor output) and leaves at t_n. Part of the pre-treated M_c becomes feed F, and is heated successively as it flows in the feed heaters from t_n to t_1 before entering the first effect. The balance (M_c - F) is rejected back to the sea.

The supplied steam S to the first effect heats the feed F from t_1 to boiling temperature T_1, and boils D_1 out of F (D_1 is the first effect distillate). The steam condensate returns back to the steam supply source. If the steam enters the first effect as saturated vapor and leaves as saturated liquid, then:

$$SL_s = FC\,(T_1 - t_1) + D_1\,L. \tag{1}$$

Vapor D_1 enters the first feed heater FH_1, preheats F from t_2 to t_1, and then flows as heating vapor to the second effect. The process is repeated to the last effect. The vapor formed in the last effect flows to the end condenser to condense. The condensate leaves and joins the distillate of other effects.

Brine B_1 from the first effect enters the second effect as feed, and brine B_2 from effect 2 is fed to effect 3, and so on to the last effect. Brine B_n from the last effect is rejected to the sea.

The feed to distillate ratio F/D is determined by the maximum allowable salinity X_b of B_n and feed salinity X_f by:

$$\frac{F}{D} = \frac{X_b}{(X_b - X_f)}. \tag{2}$$

A simplified analysis, [11], for the MEB system is given here by assuming:

1. Equal vapor generated by boiling in each effect, (other than first effect) = βD.
2. Equal boiling temperature difference ΔT between effects.

3. Equal increase Δt of the feed F in feed heaters, and $\Delta T = \Delta t$.
4. Equal specific heat C for the brine and feed.
5. Equal latent heat L and BPE.

Part of D_1 (vapor) equals to $FC(t_1 - t_2)/L = yF$, where ($y = \frac{C\,\Delta T}{L}$) is condensed in the first FH as it heats F from t_2 to t_1, and the balance ($D_1 - yF$) enters the second effect to boil the same amount. Since vapor boiled in each effect, but the first, is the same and equal to βD, then:

$$D_1 - yF = \beta D \text{ or } D_1 = yF + \beta D. \tag{3}$$

Brine $B_1 = F - D_1 = (1\text{-}y)\,F - \beta D$ becomes the feed for the second effect. Its temperature T_1 drops to T_2, by flashing yB_1, (equal to second effect flashed vapor D_{f2}). So, $D_2 = \beta D + yB_1$. Then:

$$B_2 = B_1 - D_2$$

$$B_2 = B_1 - (\beta D + yB_1)$$

$$B_2 = B_1(1 - y) - \beta D$$

$$B_2 = (1 - y)\ \left(F(1 - y) - \beta D\right) - \beta D$$

$$B_2 = (1 - y)^2\ F - \frac{\beta D}{y}\left(1 - (1 - y)^2\right)$$

and similarly

$$B_n = (1 - y)^n\ F - \frac{\beta D}{y}\left(1 - (1 - y)^n\right). \tag{4}$$

Notice that $\left(1 - (1 - y)^n\right)$ can be approximated by $\left[n\,y\left(1 - \frac{(n - 1)\,y}{2}\right)\right]$ for $y \ll 1$.

The vapor generated in the first effect, D_1 is condensed partially in FH_1 and in the second effect. Part of condensate D_1, equal to $y\,D_1$, flashes by its temperature drops from T_{v1} to T_{v2}, and enters FH_2 by flash-pot in distillate line. So, vapor inlet to FH_2 is equal to: $D_2 + yD_1 = [\beta D + y\,(F - D_1)] + yD_1 = \beta D + y\,F$, and vapor exit $= \beta D$, after condensing yF to heat F from t_3 to t_2. So, boiling vapor to each effect, but effect 1, is βD, and generates the same amount βD by boiling.

Since

$$D = F - B_n,$$

then:

$$D = F\left(1 - (1 - y)^n\right) - \frac{\beta D}{y}\left(1\text{-}(1\text{-}y)^n\right)$$

$$D = \left(1 - (1 - y)^n\right)\left(F - \frac{\beta D}{y}\right)$$

$$\frac{F}{D}=\frac{1}{\left(1-(1-y)^{n}\right)}-\frac{\beta}{y}.$$

$$\frac{\beta}{y}=\frac{1}{\left(1-(1-y)^{n}\right)}-\frac{F}{D}$$

Since

$$\left(1-(1-y)^{n}\right)=\left[n\,y\left(1-\frac{(n-1)\,y}{2}\right)\right];\ \frac{\beta}{y}=\frac{1}{\left(1-(1-y)^{n}\right)}-\frac{F}{D},$$

then:

$$\beta+\frac{yF}{D}=\frac{1}{n\left(1-(n-1)\,y/2\right)}.$$

And this is practically proportional to 1/n.

The gain ratio is determined from:

$$SL=FC(T_1-t_1)+D_1L$$
$$SL=FC(T_1-t_1)+(yF+\beta D)\,L\ .$$

$$\frac{S}{D}=\beta+\frac{yF}{D}+\frac{FC\,(T_1\text{-}t_1)}{DL}\cong\frac{1}{n}+\frac{FC\,(T_1-t_1)}{DL}. \tag{5}$$

D/S is approximated by:

$$\frac{D}{S}=\frac{n}{\left(1+n\,F\,C\,(T_1-t_1)/DL\right)}. \tag{6}$$

This shows that the gain ratio is always less than n, but close to it.

3 Typical Conventional MEB Units

Most of the new MEB units are designed with low T_1 (TBT), around 65°C, to minimize the risk of scale formation and corrosion. Since the brine temperature in the last effect T_n is in the range of 40°C, (T_1-T_n) does not allow the use of large number of effects, (typically 6 to 8), to have reasonable $\Delta T = (T_1 - T_n)/(n - 1)$ between effects, typically 4°C. The decrease of ΔT increases the specific heat transfer area ΣA/D. To keep the MEB system competitive with the MSF, its ΣA/D should be in the same range of a typical MSF units, 200-300 m^2/(kg/s). One of the main merits of the MEB system is its ability to use low temperature heat source (steam or water as a heat source) since T_1 is relatively low.

Table 1 shows samples of MEB plants including two low temperature LT plants: the Sidem 1 plant, [4], uses saturated steam at 70°C and has 12 effects, and the Ashdod plant, [5] uses hot water at 62.5°C and has 6 effects. The use of relatively large n = 12, as in the Sidem1 plant, shown in Figure 8, increases significantly the heat transfer surface areas for low T_1 as shown later.

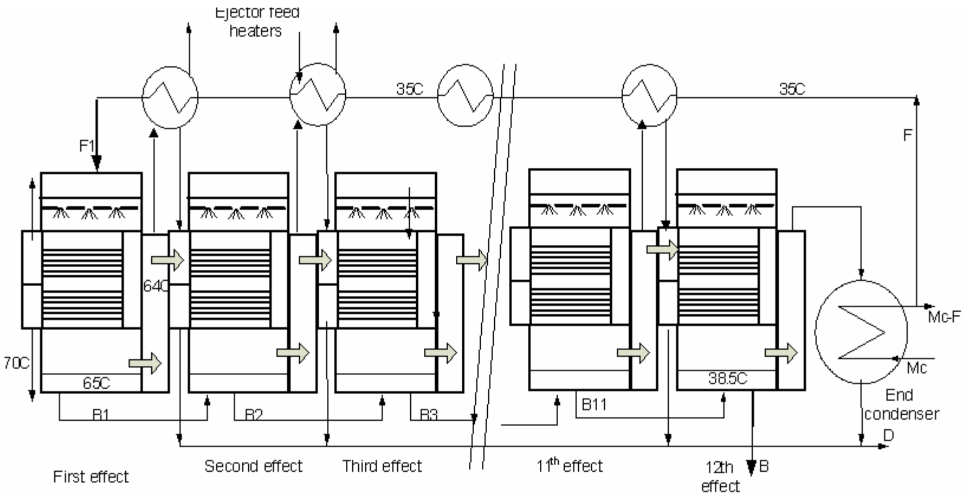

Figure 8. Forward feed of 12 effects similar to Sidem 1 Plant.

However, some designs of high T_1, large n, and high gain ratios utilize energy sources of high temperatures. As an example, Sidem 2 design [6] in table 1 has 5.5 MIGD capacity with steam supply at 110°C, 16 effects, T_1 = 106°C (TBT), parallel feed, and GR = 12.4. Another example is the Barge unit, [7] shown in Figure 9, has high TBT = 135°C, and thus allows large number of effects n = 22. It is worth mentioning here that the use of TBT higher than 110°C is risky as the reliable high temperature additives allow TBT up to 110°C.

This barge mounted unit consists of two desalting units, the first is 2-stage MVC (mechanical vapor compression) unit, and the second is 24-effects MEB unit of GR (gain ratio) = 22.3. High–Pressure steam of 50 bar, and 505°C drives a steam turbine operating the MVC unit and a generator, which produces power for the pumps of the desalting units and other barge requirements. The steam exhausted from the turbine is supplied to the MEB unit. The total nominal plant output of both MVC and MEB units is 5000 m^3/d (57.87 kg/s). No details were given on the product of each desalting unit. However, the MVC compressor suction flow rate is given as 6.2 m^3/s at 128.8°C saturation temperature, or mass flow rate of 6.2/0.693 = 8.95 kg/s, (0.693 is the vapor specific volume). Since the MVC has two stages, its MVC product output is estimated by 17.9 kg/s. So, the MEB output is 39.97 kg/s, and its steam flow rate is 39.97/22.3 = 1.792 kg/s.

Table 1. Examples of conventional multi effect desalting units.

Location, [ref.]	Ashdod, [5]	Sidem 1, [4]	Eilat, [5]	Barge unit, [7]	Sidem 2, [6]
Evaporator Type	THE	THE	THE	THE-stacked	THE
No. of effects	6	12	12	24	16
Capacity, (kg/s)	201	139	N/A	50	290
GR	5.7	9.8	10.1	22.3	12.4
Heat source	Water 2778 kg/s 63-55.4°C	Steam 14.17 kg/s, 0.31 bar	N/A	Steam	Steam
Feed TDS (g/l)	42	36	N/A	33.5	50
Feed (kg/s)	611	45.6	N/A	N/A	1502
TBT, (°C)	50	64	70 – 74	99	106
Minimum T, (°C)	34.5	37.5	N/A	N/A	46.6
Ejector steam, $\dot{m}$ (kg/s), P(bar)	0.25 kg/s at 6.6 bar	0.7 at 8 bar	N/A	N/A	N/A
Pump energy (kWh/m^3)	2.2	2	N/A	N/A	N/A
Equivalent energy (kWh/m^3)	9.1	8.14	N/A	N/A	N/A
Treatment	Poly-phosphate	N/A	Poly-phosphate	Anti-scale	N/A

The Ashdod MEB unit, in Table 1, uses hot water coming out of a power plant condenser at 62.5°C as heat source, and the TBT=50°C. Vapor is generated from this hot water by flashing as it enters a flash chamber upstream the first effect. The same idea can be used to utilize the hot water produced by the phosphoric acid fuel cells (PAFC) at 60-65°C as heat source to operate MEB system. The 6-effects Ashdod plant, in table 1, has GR = 5.7 GR, and the12-effects Eilat plant has GR = 10.1, so, as given before the GR is directly proportional to the number of effects. The use of feed heaters also affects the product output and the gain ratio GR as will be shown later by examples. The Ashdod plant has $T_o = 50°C$, and $T_n = 34.5°C$ (low), and this gives $\Delta T = 3.1°C$ for 6 effects, and if BPE = 1°C, the potential for heat transfer per effect is $\Delta Te = \Delta T - 1 = 2.1°C$ is real small and tends to increase the heat transfer area. The heat transfer area of a typical MSF of 6 MIGD is 86,661 m^2, and the specific heat transfer area is 275 $m^2/(kg/s)$, and for MEB system to remain competitive with the MSF, the specific heat transfer area should be in the same range as the MSF system.

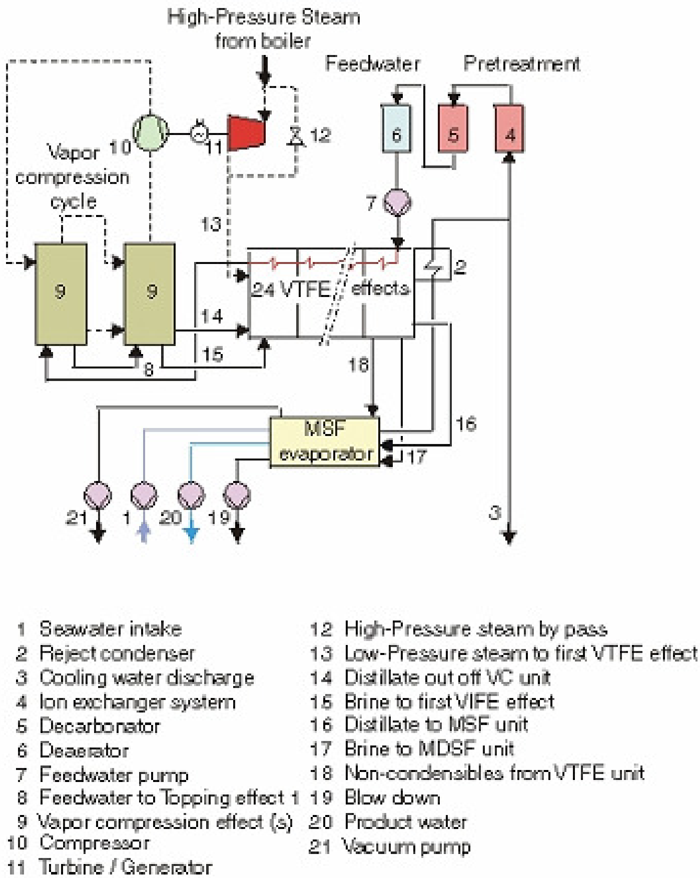

Figure 9. Barge mounted combined MEB of 22 effects and 2-effects MVC section [7].

4 Energy Consumed by MEB System

Calculations of plants similar to Ashdod and Sidem MEB plants are used here as examples to show the main characteristics of the MEB system, and to calculate roughly its consumed energy, as well as its feed to distillate ratio F/D, cooling water to distillate ratio

M_c/D, and the specific heat transfer areas. Work energy is used for pumping, and is in the range of half that used by MSF units.

Example 1

Consider a plant similar to the Sidem 12-effect units of 11 feed heaters shown in ***Figure*** 8, and use the assumptions of the given simplified analysis to find:
The temperature and salinity distribution, the gain ratio D/S, feed to distillate ratio F/D, cooling water to distillate ratio M_c/D, and the specific heat transfer area of effects and feed heaters if the overall heat transfer coefficient U_e(effect) = 3 kW/ m^2 °C, and U_f (in feed heaters and condenser) = 2.6 kWh/m^2 °C. The unit given data are: n (number of effects) = 12, output D = 500 ton/h (139 kg/s), TBT = 65°C, T_n = 38°C, t_c = 28°C, t_{12} (feed temperature at condenser exit) = 35°C, brine and seawater specific heat C = 4 kJ/kg°C, average latent heat L = 2333 kJ/kg, feed salinity X_f = 46 g/kg, and maximum salinity X_b = 72 g/kg.

Solution:

For n = 12, $\Delta T = \Delta t = (65 - 38)/11 = 2.45$°C, then

$t_1 = t_n + (n - 1)\Delta t = 35 + 11(2.45) = 62$°C,
$F/D = X_b/(X_b - X_f) = 72/(72 - 46) = 2.77$, $F = 139 \times 2.77 = 385$ kg/s,
$y = C\,\Delta T/L = 0.004$,
$\beta/y = 1/[1 - (1 - y)^n] - F/D$, $\beta = 0.074$, $\beta D = 10.234$kg/s, $D_1 = \beta D + yF = 11.854$ kg/s,
$S = D_1 + FC(T_1 - t_1)/L = 13.83$ kg/s, $D/S = 10.05$.

These calculations were used to establish Table 2 by using:

$B_1 = F - D_1$
$D_2 = \beta D + yB_1$
$X_2 = X_1\, F/B_1$
$D_i = \beta D + yB_{i-1}$
$X_i = X_{i-1}\, B_{i-1}/B_i$

To get M_c, D_{12} should be known (see Table 2):

$D_{12}(L) = M_c(4)(35 - 28)$, $M_c = 935.7$ kg/s, $M_c/D = 6.73$.

The heat transfer areas of the effects are calculated by:

Thermal load = $U_eA_e(\Delta T - BPE)$. The 1st effect thermal load = SL, and of all other effect = $D_b(L) = 2333\ \beta D$. The area of each feed heater is calculated by $F\ C\ \Delta t = U_f\ (A_f)$ (LMTD), and $LMTD = \Delta t/\ln[(T_{vi} - t_{i-1})/(T_{vi} - t_i)]$. As example for the first feed heater $T_{vi} = 65 - 1 = 64$°C, $\Delta t = 2.454$°C, $t_i = 62$°C, $t_{i-1} = 59.55$°C, and LMTD = 3.065°C, $A_{f1} = 474.36$ m^2.

The results for each effect are shown in Table 2.

Table 2. Streams temperatures, flow rates, and salinity in MEB unit similar to the Sidem plant of 12 effects and 11 feed heaters, and D=139 kg/s (D_b vapor generated by boiling, D_f vapor generated by flashing from brine, B brine, X salinity in g/kg)

Effect #	T_i	t_i	F	D_b	D_f	D	B	X	A	A_f
1	65.00	62.00	385.03	11.85	0.00	11.85	373.18	47.46	7396.8	
2	62.55	59.55	373.18	10.23	1.57	11.80	361.37	49.01	5469.6	474.3
3	60.09	57.09	361.37	10.23	1.52	11.75	349.62	50.66	5469.6	474.3
4	57.64	54.64	349.62	10.23	1.47	11.71	337.91	52.41	5469.6	474.3
5	55.18	52.18	337.91	10.23	1.42	11.66	326.26	54.29	5469.6	474.3
6	52.73	49.73	326.26	10.23	1.37	11.61	314.65	56.29	5469.6	474.3
7	50.27	47.27	314.65	10.23	1.32	11.56	303.09	58.44	5469.6	474.3
8	47.82	44.82	303.09	10.23	1.28	11.51	291.58	60.74	5469.6	474.3
9	45.36	42.36	291.58	10.23	1.23	11.46	280.12	63.23	5469.6	474.3
10	42.91	39.91	280.12	10.23	1.18	11.41	268.71	65.91	5469.6	474.3
11	40.45	37.45	268.71	10.23	1.13	11.36	257.34	68.82	5469.6	474.3
12	38.00	35.00	257.34	10.23	1.08	11.32	246.03	71.99	5469.6	474.3
Total						139			67562.4	5217.3

The results show that the total heat transfer area is 72,779 m^2, and the specific heat transfer area A/D is 523.6 m^2/(kg/s), which is 90.4% more than that of the typical MSF unit, where A/D ≈ 275 m^2/(kg/s). The high specific heat transfer area of the MEB can be tolerated due to two reasons: the heat supply here is at lower availability (has lower value) compared to the heat source for the MSF units; and the MEB unit has 25% more GR than the MSF, but A/D is still high. The main reason for this high A/D is the low heat transfer temperature difference in the evaporator $\Delta T - BPE = 2.45 - 1 = 1.45°C$ due to the large number of the used effects, n=12.

4.1. *Doubling the output same MEB unit by increasing the heating steam*

One of the main advantages of the MEB system is its operation flexibility. As an example, the Sidem plant output can be more than doubled, if it operates as 6 effects only, but the gain ratio will drop to almost half the original GR as shown in example 2.

Example 2

Assume that the steam supply to the Sidem MEB unit is increased to increase the unit output as follows: steam is supplied to evaporators 1 (of area A_1 = 7396.8 m^2) and 2 (of area A_2 = 5469.6 m^2) as the first effect, vapor leaving this effect is supplied to evaporators 3 and 4 (of 5469.6 m^2 each) as the second effect, and so on to the last 6^{th} effect consisting of evaporator 11, and 12. Similarly, feed heaters 1 and 2 (of 474.3 m^2 each) serve effect 1, and feed heaters 3 and 4 serve effect 2, and so on, but the condenser size should be enlarged after considering that feed heater 11 as part of the condenser. Also the feed should be increased to match the distillate increase. Simply, it is operating as two parallel units and each has 6 effects with its feed heaters as shown in Figure 9. Consider the overall heat transfer coefficients and the areas are almost the same as in example 1, find the new steam supply, distillate output, cooling water, and the gain ratio for the same T_o = 65°C and T_n = 38°C.

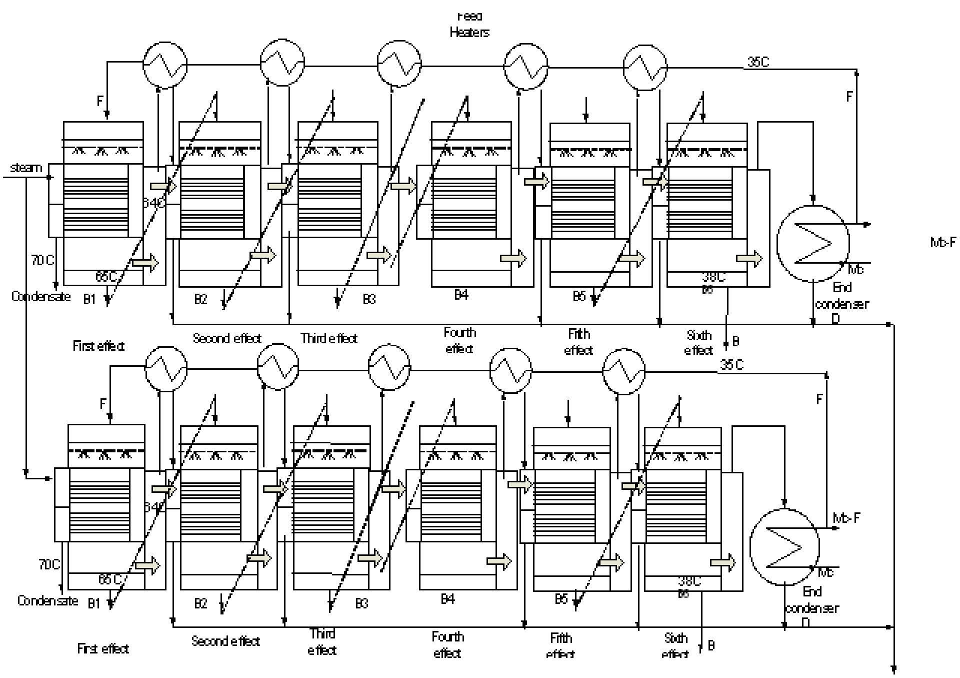

Figure 9. Operation of the Sidem forward feed with regenerative heaters, and 12 evaporators as only 6 effects.

Solution:

T_o = 65°C and T_n = 38°C. The first effect heat transfer area is 7396.8 + 5469.6 = 12866.4 m^2. The temperature difference across each effect is (65 - 38)/5 = 5.4°C. The first effect thermal load SL = U A (ΔT - BPE), and S = (3)(12866.4)(5.4 - 1)/2333 = 72.8 kg/s.

By assuming the gain ratio = 5.4, then D (to be checked later) = 393.1 kg/s, and F = 2.77×D = 1090 kg/s. SL = D_1L + F(C)(T_1 - t_1), for T1 = 65°C, t_1 = 62°C, S = 72.8 kg/s, F = 1090 kg/s, D_1 = 67.1935 kg/s, D_1 = yF + βD, y = CΔT/L = 0.00926, βD = 57.1 kg/s.

Check if the heat transfer area A_{e2} of the second effect is enough to carry the new thermal load. The second effect thermal load β D L = U A_{e2} (ΔT - BPE) = 57.1× (2333) = 3 (A_{e2}) (5.4 - 1). The required A_{e2} = 10092 m^2 is slightly lower than the available area of the two evaporator 2 × 5469.6 = 10939.2 m^2. So, evaporators 3 and 4 can do the job of the second effect in the new arrangement. The calculations are carried as before and the results are given in Table 3.

Table 3. Calculations of the streams temperature, flow rate, and salinity for the Sidem plant when operated as 6 effects

Effect #	T_i	t_i	F	D_b	D_f	D	B	X	A_e	A_f
1	65.0	62.0	1090.0	67.19	0.00	67.19	1022.8	49.0	12866.4	
2	59.6	56.6	1022.8	57.10	9.47	66.57	956.2	52.4	10092.0	1901.4
3	54.2	51.2	956.2	57.10	8.85	65.95	890.3	56.3	10092.0	1901.4
4	48.8	45.8	890.3	57.10	8.24	65.34	824.9	60.7	10092.0	1901.4
5	43.4	40.4	824.9	57.10	7.64	64.74	760.2	65.9	10092.0	1901.4
6	38.0	35.0	760.2	57.10	7.04	64.14	696.1	72.0	10092.0	1901.4
Total				352.69	41.24	393.94			63326.4	9507.0

The calculations show that the plant output almost tripled, D = 394 kg/s, but the gain ratio GR decreased from 10.05 to 5.4 (almost half), and the required heat transfer area is 72,833 m^2 is almost the same as the available 72,780. The specific area ΣA/D= 185 m^2/(kg/C) is only 35% of the 12 effect case, and 33% lower than the reference MSF unit. The cooling water requirement if t_c = 26°C is calculated by: D_6 (L) = M_c C (t_n - t_c). If t_c = 26°C, t_n = 35°C, and D_6=64.14 kg/s, then M_c = 4157 kg/s, and M_c/D = 10.55 kg/s is 56% more than in the 12-effect case.

The results show that the required heat transfer area of the effects = 63326.4 m^2 is lower than the available effects area of 67562 m^2, but the required feed heaters area is 9507 m^2, while the available area is 5217 m^2 only. There should be no problem in that as the effect area can do the job of feed heaters in the effects.

4.2. *The Effect of top brine temperature on the heat transfer areay*

Example 3

Show the effect of low (T_o - T_n) as in Ashdod plant on the heat transfer specific area, and compare it with the Sidem1 plant when operates with the same number of effects n = 6 as

Ashdod plant. The Ashdod plant data are: n=6, $T_o = 50°C$, $T_n = 34.5°C$, D = 201 kg/s, F = 611 kg/s, $X_f = 42$g/kg.

Solution:

$\Delta T = \Delta t = (50 - 34.5)/5 = 3.1°C$, then $t_1 = t_n + (n - 1)\Delta t = 32.5 + 5(3.1) = 48°C$, F/D = 611/201 = 3.04, $y = C\Delta T/L = 0.005322$, $\beta/y = 1/[1 - (1 - y)^n] - F/D$, $\beta = 0.1514$, $\beta D = 30.4326$ kg/s, $D_1 = \beta D + yF = 34$kg/s, $S = D_1 + FC(T_1 - t_1)/L = 36.09$ kg/s, D/S = 5.57. To get M_c, D_6 should be known, see Table 4, $D_6(L) = M_c(4)(32 - 26)$, $M_c = 3214$ kg/s, $M_c/D = 16$.

Due to the low $T_o = 50°C$, the specific area is 323.26 $m^2/(kg/s)$, which is almost 75% more than that of the Sidem plant (185 $m^2/(kg/s)$ when operates as 6 effects at $T_o = 65°C$. Also the decrease of T_n to 34.5°C, and even $t_c = 26°C$, $M_c/D = 16$, which is very high compared to the Sidem1 plant of 6 effect, and T_n=38°C. Results are shown in Table 4.

Table 4. Streams flow rate, temperatures, and salinity for Ashdod plant and effects and feed heaters calculated heat transfer surface areas

Effect #	T_i	t_i	F	D_b	D_f	D	B	X	A_e	A_f
1	50	47.5	611.0	33.95	0.00	33.95	577.1	44.5	11284.5	1053.4
2	46.9	44.4	577.1	30.70	3.07	33.77	543.3	47.2	9474.1	1053.4
3	43.8	41.3	543.3	30.70	2.89	33.59	509.7	50.3	9474.1	1053.4
4	40.7	38.2	509.7	30.70	2.71	33.41	476.3	53.9	9474.1	1053.4
5	37.6	35.1	476.3	30.70	2.53	33.23	443.1	57.9	9474.1	1053.4
6	34.5	32	443.1	30.70	2.35	33.06	410.0	62.6	9474.1	1053.4
						201.00			58654.9	6320.4

4.3. *The effect of using feed heaters on the gain ratio*

Example 4

Consider the Sidem plant but with parallel feeding and only 2 feed heaters; one before the first effect and another before the second effect as shown in Figure 10. The feed is heated (in the two feed heaters) by outer heat source (usually the steam coming from steam ejector used to reject the non-condensable gases of flow rate S_2). Other plant data are: TBT = 65°C, $T_n = 38°C$, t_1 (feed to the 1st effect) = 62°C, t_2 (feed to the 2nd effect) = 56.2°C, t_i (feed to effects 3 to 12) = 35°C, $X_f = 46$ g/kg and $X_b = 72$ g/kg.

Find the temperature and salinity distribution, vapor generated by boiling D_b, and by flashing D_f in each effect, and D/S, F/D, and M_c/D.

Solution:

Mass, salt, and energy balances are made to all effects. The feed flow rate F_i to effect (i), is calculated to keep X_b of the brine leaving each effect X_i less than 72 g/kg. Since $X_f = 46$ g/kg. $F_1/D_1 = X_1/(X_1-X_f)$, $F_1 = 2.77\ D_1$, then for the first effect: $SL = D_1(L) + F_1(C)(T_1 - t_1)$, S = 13.8345, D_1 = 13.64 kg/s, F_1 = 37.8 kg/s, and B_1 = 24.16 kg/s. For the second effect: $D_1(L) = D_{2b}(L)+F2(C)(T_2 - t_2)$, and $D_{f2} = B1(C)\Delta T/L = 0.1017$ kg/kg, D_{b2} and D_{f2} are the vapor generated by boiling and flashing in effect 2 respectively. In effect 2, salt in $F_2(X_f) + B_1(X_1)$ = salt out $B_2(X_2)$, or $F_2(X_f) + B_1(X_1) = (B_1 + F_2 - D_2)(x_2)$. Since $X_{b1} = X_{b2} = X_b$, $F_2/D_2 = X_{b2}/(X_{b2} - X_f)$, and F_2=2.77 D_2. $D_1(L)=(D_2 - D_{2f})L + 2.77D2(C)(T_2 - t_2)$, and $D_2 = (D_1 + D_{2f})/[1+2.77(C)(T_2 - t_2)/L]$. The last equation is generalized to give: $D_i = (D_{i-1} + D_{if})/[1 + 2.77\ (C)(T_i - t_i)/L]$.

Table 5 gives the temperature and salinity distribution, feed F_i to each effect, and distillate generated by boiling D_{bi}, and by flashing D_{fi}. The results show that D = 137.86 kg/s and total feed F = 383.53 kg/s. The steam supply to the two feed heaters S_2 is calculated by: $S_2(L) = (F_1 + F_2)\ (C)(t_2 - 35) + F1(C)(t_2 - t_1)$, S_2 = 3.1 kg/s, total S = 16.93 kg/s, and D/S = 7.78, and F/D = 2.784.

This example shows that the use of feed heaters increases the GR 29% (from 7.78 to 10.05) compared to the case when no feed heaters were used.

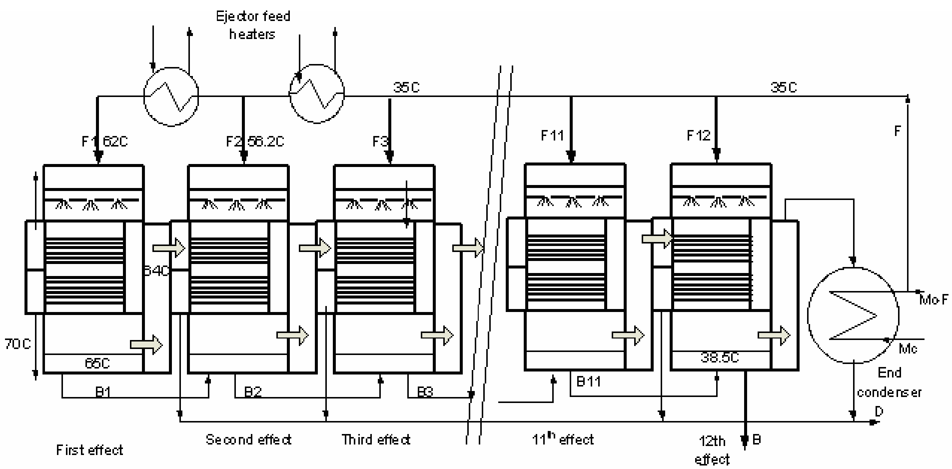

Figure 10. Parallel feed 12-effects desalting system with only feed heaters

Mass, salt, and energy balances are made to all effects. The feed flow rate F_i to effect (i), is calculated to keep X_b of the brine leaving each effect X_i less than 72 g/kg. Since $X_f = 46$ g/kg. $F_1/D_1 = X_1/(X_1-X_f)$, $F_1 = 2.77\ D_1$, then for the first effect: $SL = D_1(L) + F_1(C)(T_1 - t_1)$, S = 13.8345, D_1 = 13.64 kg/s, F_1 = 37.8 kg/s, and B_1 = 24.16 kg/s.
For the second effect: $D_1(L) = D_{2b}(L)+F2(C)(T_2 - t_2)$, and $D_{f2} = B1(C)\Delta T/L = 0.1017$ kg/kg, D_{b2} and D_{f2} are the vapor generated by boiling and flashing in effect 2 respectively.

In effect 2, salt in $F_2(X_f)$ + $B_1(X_1)$ = salt out $B_2(X_2)$, or $F_2(X_f) + B_1(X_1) = (B_1 + F_2 - D_2)(x_2)$. Since $X_{b1} = X_{b2} = X_b$, $F_2/D_2 = X_{b2}/(X_{b2} - X_f)$, and F_2=2.77 D_2.
$D_1(L)=(D_2 - D_{2f})L + 2.77D2(C)(T_2 - t_2)$, and $D_2 = (D_1 + D_{2f})/[1+2.77(C)(T_2 - t_2)/L]$.
The last equation is generalized to give: $D_i = (D_{i-1} + D_{if})/[1 + 2.77 (C)(T_i - t_i)/L]$

Table 5 gives the temperature and salinity distribution, feed F_i to each effect, and distillate generated by boiling D_{bi}, and by flashing D_{fi}. The results show that D = 137.86 kg/s and total feed F = 383.53 kg/s. The steam supply to the two feed heaters S_2 is calculated by: $S_2(L) = (F_1 + F_2) (C)(t_2 - 35) + F1(C)(t_2 - t_1)$, S_2 = 3.1 kg/s, total S = 16.93 kg/s, and D/S = 7.78, and F/D = 2.784.

This example shows that the use of feed heaters increases the GR 29% (from 7.78 to 10.05) compared to the case when no feed heaters were used.

Table 5. Temperature, salinity, feed, distillate by boiling D_b, and by flashing D_f, and brine from effects of example 4.

Effect #	T_i	T_{vi}	F_i	Ti (feed)	D_b	D_f	D	B_i	X_i
1	65.00	64.00	37.80	62.00	13.64	0.00	13.64	24.16	71.97
2	62.55	61.55	37.12	56.20	13.24	0.10	13.40	48.56	71.98
3	60.09	59.09	33.82	35.00	11.95	0.20	12.21	73.47	71.98
4	57.64	56.64	31.44	35.00	10.99	0.31	11.35	95.94	71.98
5	55.18	54.18	29.84	35.00	10.32	0.40	10.77	116.61	71.98
6	52.73	51.73	28.91	35.00	9.90	0.49	10.44	136.02	71.99
7	50.27	49.27	28.56	35.00	9.69	0.57	10.31	154.61	71.99
8	47.82	46.82	28.75	35.00	9.68	0.65	10.38	172.79	71.99
9	45.36	44.36	29.45	35.00	9.85	0.73	10.63	190.91	71.99
10	42.91	41.91	30.67	35.00	10.22	0.80	11.07	209.29	71.99
11	40.45	39.45	32.42	35.00	10.77	0.88	11.71	228.25	71.99
12	38.00	37.00	34.75	35.00	11.53	0.96	12.55	248.13	71.99
Total			383.53		131.76	6.10	137.86	385.99	

5 Equivalent Work Consumed by the MEB System

The Sidem 1 unit is designed to operate by low-pressure steam extracted from steam turbine at 0.3 bar, (saturation temperature of 70°C). The plant capacity is 2.64 MIGD. The thermal energy consumed by the system according to design is 51 t/h (14.17 kg/s) steam of 2498 kJ/kg enthalpy and 0.3 bar and the leaving condensate has 294 kJ/kg enthalpy. The distillate output is 500 t/h (138.89 kg/s), and this gives specific thermal energy of 217.4 kJ/kg distillate. If this MEB unit is combined with one of the steam power plants in Kuwait, shown in Figure 11, it can be supplied with steam at 70 °C extracted from the LP steam turbine as heat source. This steam would produce work if it expands to the condensing pressure in the LP turbine. This work is considered as work loss due to steam extraction to the desalting unit, or work equivalent to the thermal energy supplied to the unit.

This work loss is equal to the steam enthalpy difference between the extraction point (2580 kJ/kg) and at the condenser inlet (2346 kJ/kg), as shown in Figure 12. So, the work loss due to extraction per kg of steam is equal to 234 kJ/kg. Since the gain ratio calculated in example 1 is 10.05, then the specific equivalent work is 23.3 kJ/kg distillate. By adding 7 kJ/kg pumping energy, the total specific equivalent work becomes 30.3 kJ/kg distillate (equivalent to 8.4 kWh/m^3 distillate). This is almost 40% of the work equivalent consumed by a typical MSF system, (about 21 kWh/m^3), but still 40 - 60% higher than that of the very efficient reverse osmosis RO system (about 5 - 6 kWh/m^3).

Table 6, [8], shows the enthalpy of steam at the extraction point (at 70°C), at condenser inlet, the work loss per kg of steam and per kg distillate and the total specific equivalent work at different power loads of the power plant.

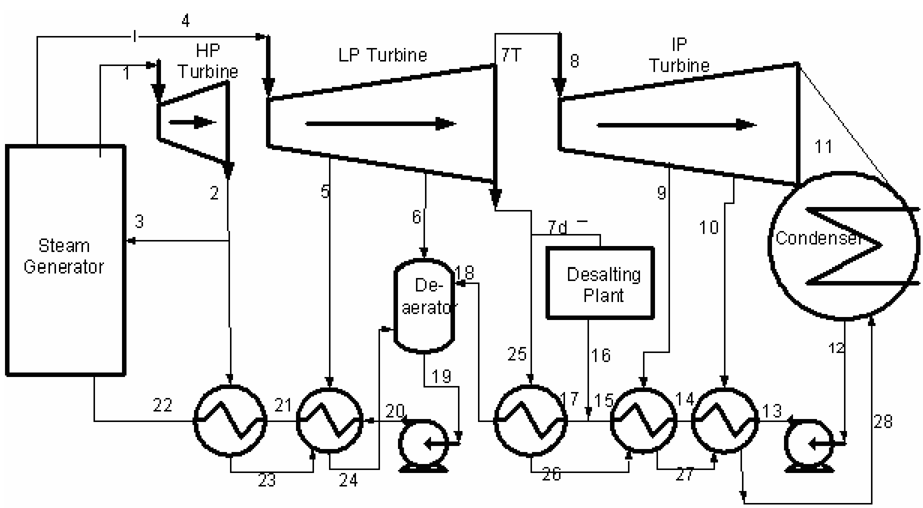

Figure 11. Cogeneration power desalting plant used to supply steam to MSF units, the expected supply to the MEB from point 10.

The Ashdod plant operates at lower temperature heat source, 62.5°C, and its GR = 5.6, [5], and the work equivalent to the thermal energy supplied to the unit is 7.65 kWh/m^3, and the pumping energy is 2.5 kWh/m^3, (based on 1800 kW pumping energy), a total of 10.15 kWh/m^3. This is less than half of the work equivalent used by a typical MSF unit, although its GR is 5.7, and that of MSF is 8.0. This shows that the Ashdod plant of 5.7 GR is more than 100% efficient than the MSF unit of 8.0 GR.

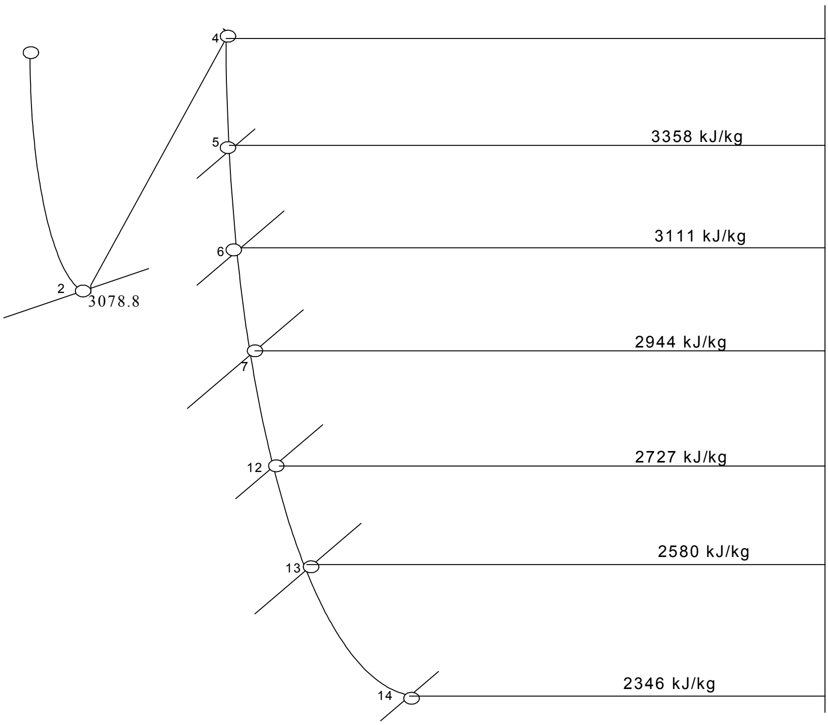

Figure 12. The enthalpy of extracted steam from the cogeneration power desalting plant at different electric load.

Table 6. Enthalpy of steam extracted from the turbine to the MEB at different load of the turbine and corresponding equivalent work, and specific fuel energy.

Load %	$h_{extraction}$ (kJ/kg)	$h_{condenser}$ (kJ/kg)	work loss (kJ/kg $_{steam}$)	specific equivalent work (kJ/kg $_{distillate}$)	Total specific equivalent work (kJ/kg $_{distillate}$)	total specific equivalent work (kWh/m$^3_{distillate}$)	Specific fuel energy input kJ/kg
100	2550	2340	210	20.89	27.89	7.75	77.5
80	2550	2335	215	21.39	28.39	7.89	78.9
50	2630	2500	130	12.93	19.93	5.54	55.4
25	NA	NA	NA	NA	NA	NA	

Pumping energy is used by the MEB system to move its streams, and is usually about half that used in the MSF system. The reported specific electric power consumed for three MEB units operated in St. Thomas (209.4 m^3/h capacity), St. Croix (207 m^3/h), and St. Thomas II (213 m^3/h) are 1.75, 1.8, and 1.75 kWh/ m^3 respectively, while the design figure for the three units is 2.5 kWh/ m^3, [9]. The specific fuel energy can be calculated by multiplying the specific work equivalent in kWh/m^3 by 3.6 to convert to kJ/kg work, and divided by 0.36 (the typical efficiency of power plant to get the specific fuel energy in kJ/kg). The available energy of steam supplied at 0.3 bar can be calculated by: 2336.1[1 – (25 + 273)/(69 + 273)] = 300 kJ/kg, where 2336.1 is the latent heat in kJ/kg for P = 0.3 bar. For GR = 10.05, the specific available energy per kg distillate A_d/Dis 300/10.05 = 29.9 kJ/kg or 8.3 kWh/m^3.

6 Conclusion

In conclusion, the conventional MEB has the advantage of using low temperature heat source (steam or hot water) when it operates at low TBT, and this can give much lower equivalent work or available consumed energy than the MSF units. The decrease of ΔT to less than 2°C significantly increases the heat transfer areas. The use of feed heaters enhances the GR, but adds more complexity, capital cost, and pumping energy. This system consumes about half the pumping energy of the MSF. The MEB can be arranged to give much more product when needed, but at lower GR.

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DESALINATION AS A SUSTAINABLE SOURCE OF FRESH WATER PROVISION?

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This paper analyzes the potential role of desalination as a sustainable source of fresh water provision, starting from the present framework and considering the trends in the desalination technology. Several aspects have been reviewed: the state of the art of the technology, focusing the attention on the most widespread desalination technologies; the importance of desalination in the different regions of the World and the future trends; the economic costs of desalted water and the uses derived from those costs, the environmental charges provoked by desalination and their possible corrective measures to be undertaken; future improvements expected for desalination technology, and their economic consequences. Particular attention is focused to environmental issues and integration of desalination with other productive processes, particularly with energy production systems as a mean of dramatically reduce the environmental loads provoked by desalination systems.

1 Introduction

The rapidly demographic growth, the important economical growth in developing countries (e.g. GDP in China and India is experiencing a continuous growth of about 9% and 7% respectively [1]) and the pollution of fresh water resources are identified by UN as the main causes of the World crisis that humankind will suffer during the next decades, particularly due to the increasing fresh water scarcity in many regions of the Planet.

Humans are using at present about 4,000 km^3/year [2], being the world's renewable fresh water resources that can be technically used about 10,000 km^3/year [3]. If the efficiency of fresh water use is not improved in the next years, the picture of fresh water availability for all the inhabitants in the World is really dark. Figures show that nowadays, 30% of the world's population is suffering water stress, 3 billion people lack appropriate

† Work partially supported by the Spanish Ministry of Science and Technology.

water sanitation and 12% of the world population uses about 85% of the water consumed [4].

Desalination, which is of continuous increasing importance, represents a possible and very interesting alternative for increasing them. Particularly if it is taken into account that more than 70% of World population is living at a distance lower than 70 km from coastal areas. More than 30-fold increase in global capacity over three decades occurred [5], but yet desalinated water represents only about 0.2-0.3% of the fresh water used worldwide, and about 3% of global drinking water.

Nevertheless, desalination is an energy intensive process, which is usually driven by conventional energy sources (basically fossil fuels). On average, 3.5 liters of oil are required per cubic meter of desalted seawater. As a consequence, producing the total amount of desalted water in all of the facilities in the world requires a huge amount of energy, which is approximately equivalent to the 0.3-0.4% of primary energy in terms of fossil fuels consumed all over the world [6]. Thus, the future of desalination, is closely linked to the problem of conventional energy source availability, possible depletion and cost as well as the environmental impacts (including the trend to minimize CO_2 emission in order to reduce the greenhouse effect).

Furthermore, the associated economic costs of desalination (investment and operation costs), sometimes higher than conventional water supply techniques, could limit its expansion in the less-developed countries, and consequently the gap between the First and the Third World could be enhanced. The present situation demands for imaginative solutions, for instance process integration or the use of renewable energy sources to produce desalted water, in order to prevent from more profound economic and social effects.

In this paper is analyzed, from technological, economic and environmental viewpoints, the role of desalination in the context of sustainable fresh water provision. It is presented first the present state of the art of the technology, including a technical and cost analysis, and how it is used in different parts of the World, followed by a detailed environmental analysis, applying the Life Cycle Assessment technique that explores the potential of reducing its environmental impact, including as well suggestions about possibilities of achieving a more sustainable use of desalination.

2 Most important commercial desalination technologies

A very interesting and comprehensive review of desalination technologies can be found in reference [7]. Here, most important commercial desalination technologies used nowadays are reviewed. They are two main groups depending on the energy required: a) thermal desalination technologies and b) mechanical driven processes.

2.1. *Thermal Desalination Technologies*

<u>Multi-Stage Flash (MSF) Distillation</u>: Is the most widely form to produce water from seawater, especially common wherever the temperature, salt content, biological activity or

pollution level of seawater is high, as in the Arabian Gulf Area. This process has been in large-scale commercial use for over 30 years, mainly coupled to power stations. In general, MSF plants are more common because they are simple and robust, although their specific consumption may be higher than other technologies. Other advantage of MSF plants are their unit size, considered of large scale (more than 50,000 m^3/d of capacity per unit). In the MSF process (see Figure 1), seawater pumped through heat exchanger tubes installed in the various evaporator stages, is heated to a certain temperature. Final heating is performed by steam (usually coming from a power station) in a brine heater. The hot seawater then goes into flash chambers, and part of the brine flashes into vapor and after passing a demister, it condenses outside the tubes while heating the seawater flowing through the tubes. The MSF unit contains cells assembled in series, at a different pressure. Distillate produced is collected in a channel mounted below the tube bundle. Brine recycle is adopted to reduce seawater needed to produce fresh water. The concentrated seawater (blowdown) is also removed from the last stage by a pump or by gravity.

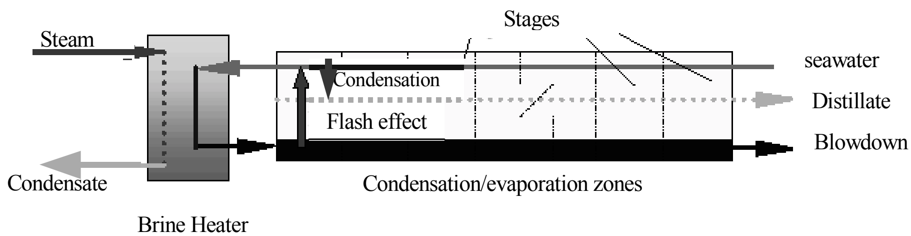

Figure 1. Diagram of a typical MSF unit.

<u>Multi-Effect Distillation (MED):</u> Contrary to MSF, in Multi-Effect Distillation (MED) evaporation takes place on surfaces, by exchanging the latent heat through the heat transfer surface between condensing vapor on one side and evaporating brine on the other. The MED plant also has several stages (see Figure 2), each with a heat exchanger tube bundle. In horizontal-tube disposition, seawater is sprayed onto the tubes and the condensing heating steam inside the tubes evaporates part of the seawater on the outside. The steam produced is used as heating steam in the next stage, where it condenses inside the tubes. Condensate is the water product. Obviously, the boiling temperatures and pressures in the different evaporators cannot be the same. The first stage is heated by external steam from a heat recovery steam or a back-pressure steam turbine, but in most cases, MED plants are equipped with thermal vapor compressors for better efficiency. Steam produced in the last stage is condensed on the outside of exchanger tubes in a separate condenser, which is cooled by incoming seawater. The major advantage of MED with respect to MSF is their productivity (water produced per steam required, Gain Output Ratio, GOR): MED plants could reach a value of 15 while MSF almost 10, and includes lower specific power consumption in pumps (< 2 kWh/m^3) than MSF (> 3 kWh/m^3). Furthermore, GOR does not depend on the steam temperature coming from the

turbines as MSF plants, therefore MED plants are the most promising distillation technologies for desalination. However, at present the unit size of MED plants is up to the third with respect to MSF units.

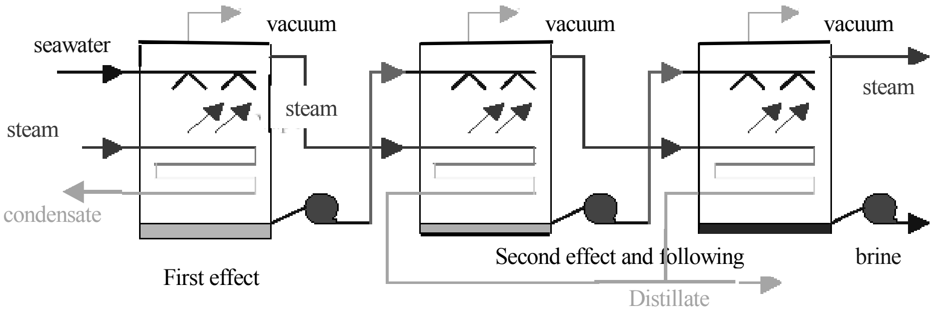

Figure 2. Diagram of a MED unit.

2.2. *Desalination technologies driven by mechanical or electrical energy*

Vapor Compression (VC) distillation. Is similar to multi-effect distillation (MED), but the main difference is that the vapor produced by the evaporation of the brine inside is not condensed in a separate condenser: that vapor enters in a centrifugal, single-stage type designed for high-volumetric flows, and this compressed steam is discharged into the evaporator onto the outside of the tubes, where it condenses and provide its latent heat energy to boil seawater inside of the tubes. Note that the process only supplies thermodynamic losses and then lower energy requirements (up to 9 kWh/m^3 of product). Unfortunately, the VC size is limited by the compressor and it is only about 3.000 m^3/d.

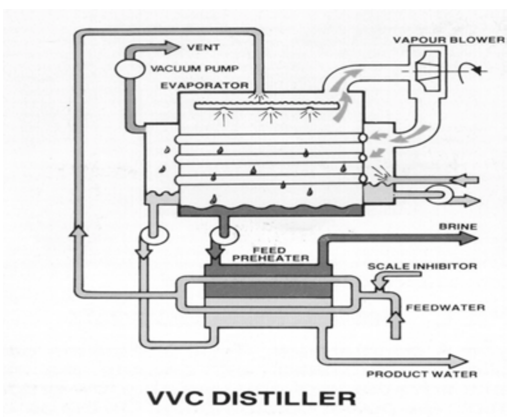

Figure 3. Typical one-stage vapor compressor distiller.

<u>Reverse Osmosis (RO).</u> In RO desalination (see Figure 4), seawater (or brackish water in case of inland territories with saline aquifers) is pretreated to avoid membrane fouling. It then passes through filter cartridges and is sent by a high-pressure pump through the membrane modules, and pure water permeates through the membranes and seawater salt is concentrated (brine). Permeate flows into a storage tank, and pressurized brine is sent via an energy recovery system (ERS) back into the sea. Seawater RO process (SWRO) only consumes power (mainly in HP pump), but ERS [8, 9], e.g. Pelton or Francis turbines, inverse pumps or pressure exchangers, could recover more than the 95% of the energy stored in the rejected brine. Then, total energy consumption for SWRO could be 3-5 kWh/m^3, depending on the feed water salinity and temperature. Its modularity allowed a rapid expansion in all over the world. Other membrane processes as nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) are rapidly growing to be used in brackish desalination or waste water reuse, with very low energy consumptions (< 1 kWh/m^3).

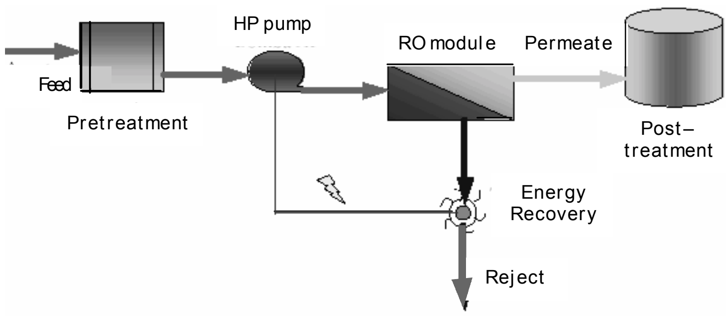

Figure 4. Diagram for a seawater RO unit.

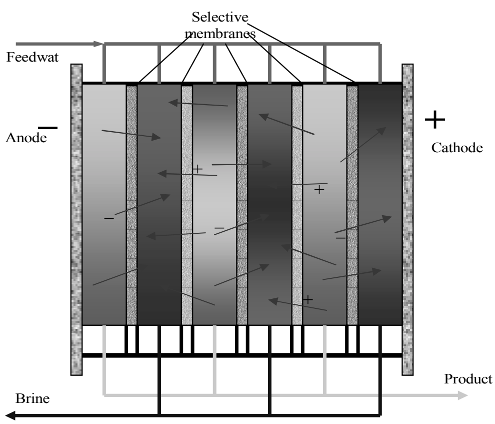

Figure 5. Principle of operation of a single ED cell.

<u>Electrodyalisis (ED).</u> It demineralizes brackish water by making different ions migrate through an electric field created by two electrodes. If not constrained, these ions discharge on the electrodes of opposite sign, and if a set of selective and permeable membranes is placed between the electrodes, salt concentration decreases in some compartments of the cell and increases in some others. ED is suitable for desalt waters with a salt content between 1 to 3 g/l (ED not profitable for seawater) with a very low power consumption (less than 1 kWh/m^3) and a salt rejection of more than 80%.

2.3. *Comparison of desalination technologies*

Next table include some keys of the previously referred processes, noting that SWRO is really more convenient than other processes with respect to energy requirements.

Table 1. A comparison between the most widespread desalination processes. (a) Power produced in a conventional power plant with 30% efficiency. (b) Desalination process in dual plant. (c) Including energy recovery system in the RO process.

Desalination Process	Thermal Processes		Mechanical Processes		
	MSF	MED-TVC	VCa	ROa	EDa
Power consumption (kWh/m3)	3-5	1-2	8-12	3-6	0.8-1.5
Primary energy consumption (kJfuel/kgwater)	400-500 200-300b	350-400 200-250b	100-200	70-90 30-50c	10 - 18
Operation temperature (º C)	110	70	70	45	45
Raw water quality (ppm)	>50,000	>50,000	>50,000	< 50,000	< 3,000
Product quality (ppm)	< 50	< 50	< 50	< 500	< 500
Unit capacity (m3/d)	10,-50,000	5,-20,000	1,-5,000	10,-100,000	1,-10,000
Plant reliability	high	high-medium	low-medium	high-medium	high
Modularity	difficult	difficult	difficult	easy	easy

3 Desalination in the world

The information about the state of the art of the world market for all types of desalination plants can be found in the IDA Worldwide Desalting Plants Inventory, compiled by Wangnick [5]. This inventory report (No. 18) shows that by the beginning of the year 2004, a world-wide total of 17,348 desalinating units with a total capacity of 37,750,000 m^3/d have been installed or are under construction. Seawater plants (SWDP) produced around the 60% of the total capacity and the remaining 40% are other types of water. According to that inventory, the proportions of the various processes have been changed along the time. Now, 47.2% are RO plants and only 36.5% are MSF units, but ten years ago that proportion was 32.7% and 51.3% respectively. If only seawater desalting plants are considered, the figures are 61.7% for MSF units and 26.7% for RO plants, but the ratio was 80% for thermal plants and 20% for membrane plants ten years ago. Next is presented a summary of the present situation of desalination in diverse worldwide regions.

The Middle East States (ME) are the biggest users of desalination technology with more than 50% of the total capacity in the world. Thermal processes are preferred because of the existing good experience in the region, and the difficulty of the gulf seawaters (high temperature, salinity and amount of biological matter) for using the RO process since ten years ago, as well as the low cost of energy. The Kingdom of Saudi Arabia, supported by several MSF units combined with power generation in dual purpose plants, had in 2004 the 17.4% of the World capacity. The third world producer are the United Arab Emirates (UAE), with a rank of 14,7 % of the total installed capacity (desalted seawater per capita reaches 2 m^3/day). Kuwait only incorporates MSF distillers (88) up to the 5.8% of the worldwide capacity (315.6 MGD in 2003) [10]. Some other ME countries as Qatar, Bahrain (with a capacity of 335,000 m^3/d [11]) and Oman complete a set depending on desalted seawater resources. The majority of installations are composed by huge dual-purpose power and desalination plants. In reference [12] can be found a detailed contribution of desalination here. Privatization of water and energy suppliers is now common in the area, taking into account the continuous growing demands of water and energy and the constraints that suffer the public financial resources.

USA has the second rank in the world capacity, with 16.2% of the overall score and more than 3,000 plants [5]. Here, it is only representative desalination of brackish aquifers or degraded aquifers by seawater intrusion (ED, RO), as well as membrane softening techniques (MF, NF or UF) which remove bacteria, viruses and ions. Evaporation techniques are not favored due to its lack of competence with respect to membrane technologies [13], and ED/EDR can not stop pathogens: RO/NF/UF and MF will be widely used in big plants (more than 10,000 m^3/d) to reduce salinity of brackish waters or reuse waste water directly. SWRO plants are planned only for big plants in Texas, California and Florida.

Regarding the region of Latin America and Caribbean [14], only in the Caribbean desalination is really important to supply water driven by the growing tourism and decreasing costs. The total installed capacity in the Caribbean is 724,000 m^3/d by the year 2000, the most important facilities are settled at the Netherlands Antilles, Virgin Islands and Trinidad, with more than 110,000 m^3/d. In consonance with the Canary Islands, the Caribbean has been the cradle to prove the technological developments of desalination along the time: the first SWRO market, the first low-temperature MED units, the implementation of the BOOT (Build, Own, Operate and Transferred) contracts. The future in this area is the continuous growth of desalination, the majority of them based on BOOT contracts till reaching self-sufficient islands, favored by the decreasing trends of seawater desalinated costs. On the other hand, desalination in Latin America does not represent an equal weight that in the Caribbean (530.000 m^3/d), although the capacity increase in the recent years is also significant. The two main contributions come from Chile (131,000 m^3/d, mainly for industrial purposes) and Mexico (a capacity of 285,000 m^3/d for industrial uses and tourism resorts). The future of desalination here is linked to remove contamination more than reduce salt content with membranes. SWRO plants will growth but not significantly for supplying industries and covering new tourist demands.

In Asia, Japan leads the installed capacity in the region with more than 1 Mm^3/d and more than 1,200 units. Only two big plants (40,000 m^3/d and 50,000 m^3/d) are used for domestic use, but several small plants exist in remote areas such as small islands. Electronics industry consumes ultra pure water and softening techniques are applied from pure or river waters in a great scale. In China the majority of desalination plants have industrial or power generation uses [15] consuming brackish, river, pure or waste waters in RO processes, and only two municipalities and two tourism facilities exist. Similar situation can be found in other countries of this area, e.g. Korea, Indonesia, and so on. In general the future of desalination industry in that area is focused on the industry requiring ultra pure water, although demand for desalination will occur in some areas of highly dense population and high income. A great expansion of seawater desalination is not foreseen for the next future, especially for China and India since big hydraulic were projected to provide fresh water.

As it is expected, desalination in Europe is focused in the Mediterranean countries, where climatologic conditions and economic activities (tourism and agriculture) demand huge water volumes. Spain is the dominating country with almost a 6.4% worldwide capacity at the end of 2003 [5] representing more than the 8% of the urban consumption. Desalted water has even irrigated high-profitable crops in the South-East of Spain and the Canary Islands. Several innovations have been proved, and the future is really promising, for instance the Hydrologic Plan A.G.U.A. includes 17 new big desalination plants that will provide up to 621 hm^3/year for the Mediterranean area. By far, the second on that list is Italy with a total capacity of 400,000 m^3/d, most of their plants located at the south of the country and the island territories. The third and fourth places are occupied by two Mediterranean islands, Malta and Cyprus, it suppose more than 50% of its resources. Greek islands are quite similar to those ones. Russia only has a reduced capacity of their desalination plants with a total value of about 100,000 m^3/d composed by several old MED plants located at the Caspian and Black Sea. In Central Europe, Germany, Austria and Netherlands have several plants to recycle wastewater or produce pure water for industrial processes including power generation.

Turkey, Jordan and Lebanon are other countries that also have small RO desalination plants. However, Israel has planned a major program of seawater desalination to provide new 400 hm^3/y in 2002-2010, from series of 6 large plants of 45-100 hm^3/y to partly balance the water scarcity problems in the country [16].

The geographical situation the North Africa (NA) region could be characterized as similar to the Middle East, but seawater water production is almost negligible with respect to that area, mainly due to their financial constraints. The estimated cumulative installed desalination capacity reached 1 Mm^3/d at the end of 1995 [17]. More than 625,000 m^3/d are located in Lybia (mostly MSF plants for municipalities), 192,000 m^3/d in Algeria mainly for industrial purposes. Egypt incorporated 95,000 m^3/d at the end of 1999, with small RO plants and MSF/VCD plants, and finally Morocco and Tunisia reported respectively 64,000 m^3/d and 47,000 m^3/d of installed capacity at the end of 1995. The future of desalination in this area is also focused on the tourism locations (Tunisia and Egypt) that even include brackish water plants, and the increasing applications of the solar energy in remote and dessert areas for small locations.

4 Desalination Costs

The economics of desalination vary form country to country, depending upon the opportunity cost of energy and capital as the main factors of production, and the type of desalination process. In case of dual-purpose plants, in which water and power are two separate products, energy cost of desalted water could give to controversy. Moreover, the progressive privatization of the public sectors in the ME Countries allowed under different contracts the operation and control of new big power and desalination plants or rehabilitated existing ones: the new independent water and power projects (IWPP) permits the fulfillment of the continuous growing demand for water.

4.1. *Investment costs*

Breaking the desalination costs of water, the total costs can be divided in capital costs (up to 40%) for interest and depreciation due to the plant investment and the rest are considered running (or operating) costs. The investment costs for seawater desalination plants have decreased over the years thanks to the technological improvement. Specific costs close to 1,000 €/(m^3d) could be obtained for large distillation units in ME, whereas in Mediterranean countries SWRO could be constructed below 600 €/(m^3d). The next table shows the expected range for different desalination processes and plant sizes.

Table 2. Investment cost of seawater desalination plants depending on the type of process and expected plant size [18].

Technology	Capacity range (m^3/d)	Specific investment cost (€/m^3·d)
MSF	10,000-50,000	1,680-1,080
MED-TVC	5,000-20,000	1.080-800
VC	1,000-5,000	1,500-1,020
RO	10,000-100,000	900-550

The investment costs of the plant can be broken into the following sub-systems:

- The raw water supply system includes the seawater intake structure. It could suppose a high percentage if the specific seawater flow is high and the sea shore is very shallow (up to 30%), but they could be reduced if the water intake is shared with other plants, as the cooling system of the required power plant or hybrid plant.
- The pre-treatment system is very low for thermal plants and consists of simple equipment to storage and dose some additives (antiscale, antifoam and sodium bisulphite). However, in RO plants costs are considerably higher (up to 20%) because the raw seawater must be carefully treated (chlorination, filtration, acidification, inhibition by polyphosphates and dechlorination) before entering the RO racks.
- The desalination system, by far the most expensive system of the plant. For thermal plants the elevated heat exchange area and fine materials required implies that those costs contribute to more than the 70% of the investment. The weight of the membrane costs and the high-pressure pump, as soon as the energy recovery system for RO plants does not sum up the same contribution (a maximum of 60%).

- The brine disposal system for thermal plants could be shared with the cooling water outfall (seawater) and therefore it is not representative for those plants. However, for RO brine discharge is almost double concentrated than feed water and specific design is required to avoid any damage in endemic flora species (the cost of that system could be increased up to 5-7% of the total investment).
- The post-treatment system applied to the produced water is quite simple but it is obliged by the purity of desalted seawaters. Usually, desalted water is re-hardened by adding carbon dioxide and lime, and finally is disinfected with chlorine. In some cases, caustic soda is also added to increase pH, in order to compensate the effect of the acid previously dosed. Anyway, its contribution is not significant.
- The storage system of the drinking water produced consists of cylindrical tanks with a capacity up to 24-48 hours of water production, contributing no more than the 3% of the total investment required.
- The auxiliary equipment (instrumentation, electrical connections, air and oil systems) as soon as the civil works required for a desalination plant could suppose up to the 10% of the total investment of the plant.

4.2. *Operation costs*

The long list of components that contains the operating (or running) costs are:

- Energy cost is usually more than 50% of the total cost of operation, although its weight depends on the location of the plant. In oil-poor countries, RO is always the best solution. Note that energy prices trend will raise in the near future due to the politic instability and the application of the Kyoto Protocol.
- Personnel costs decrease as the plant size grows, except for very small plants in where personnel are shared with other activities.
- Chemical costs are not important for thermal plants, since only antiscalants and antifoams are added to raw water, but it is representative for membrane plants: MF or UF techniques could reduce that operation cost but increase the corresponding investment. Similarly, cleaning costs (chemical or washing with brine) are higher in case of membrane plants.
- Membrane replacement in RO plants could suppose an important item if inadequate cleaning control is given. The rest of consumables are almost economically negligible in membrane but also for thermal plants.
- Finally, the annual costs for spare parts can be calculated from 1 % to 3 % of the total investment, depending on the plant size.

4.3. *Total costs*

Summarizing, the total (investment + operating) costs for a typical thermal and membrane plant (RO) could reach to 0.7 and 0.45 $\$/m^3$ respectively. Note that costs could vary from country to country, as we can see for the present RO projects presenter under BOOT contracts (see Table 3).

Table 3. Large desalination plants projected or under construction with BOOT projects (*) A normalized cost of energy (0,04 c$/kWh) has been used. [20]

SWDP	Tampa bay	Trinidad	Larnaca	Dhekelia	Singapore	Askhelon	Algeirs
Capacity (m^3/d)	95,000	135,000	40,000	40,000	136,000	274,000	200,000
Feedwater salinity (ppm)	26,000	38,000	40,000	40,000		40,000	40,000
Contract Year			2000	1996	2002	2002	2003
Years of contract	30	23	10	10	20	25	25
1^{st} year price*	0.46	0.71	0.73	1.09	0.45	0.52	0.818

It is important to remark that technological developments have consistently reduced the costs of desalted water: for instance, in Spain, 20 years ago the cost of desalination was around 2.0-2.1 €/m^3 (with old MSF units) and now that cost is four times less [18].

5 Environmental Assessment

The environmental charges associated to the desalination processes differ from each process and location. However, two major cases could be identified, taking into account the geography and the dominant technology involved: a) The Arabian Gulf Area, in which distillation processes are mainly installed in relatively closed seas suffering dessert climate, and b) the rest of the World with RO as the dominant technology installed in big oceans or seas. In both cases, two effects should mainly be studied: the energy consumption of the desalination plant and the brine discharges of plant, as soon as some other minor consequences derived from the chemical treatments and cleaning systems and the noise provoked.

In the Middle East zone, and particularly the Arabian Gulf, the long list or large distillation plants (MSF) is provoking a serious environmental impact in that area where the economic growth of new formed countries is jeopardizing its sustainable development [21]. In this area, distillation plants discharge brine with a concentration of about 60,000-65,000 ppm starting from raw seawaters of 40,000-45,000 ppm, therefore salt dilution in the sea is not very problematic, taking into account the scarce flora of the Gulf soils. Thermal pollution is an additional impact associated to distillation plants since brine is usually discharged from 5 to 7º C above the raw seawater temperature. Furthermore, those plants, which are driven by fossil fuels have therefore a very important primary energy consumption (see Table 1) and as a consequence the associated emissions of pollutant gases as CO_2 and NO_x (see Table 4) are very significant as well.

Table 4. Relevant airborne emissions produced by different desalination technologies applying the Life Cycle Assessment technique [23].

	MSF	MED	RO (4 kWh/m^3)	RO (3 kWh/m^3)	RO (2 kWh/m^3)
kg. CO_2 / m^3	23.41	18.05	1.78	1.73	1.20
g. NO_x / m^3	28.30	21.43	4.05	3.92	2.74
g. NMVOC / m^3	8.20	6.10	1.15	0.76	0.52
g. SO_x / m^3	28.1	26.31	11.13	11.86	9.08

The situation in the other countries is less dramatic than in Arabic countries. The primary energy consumption of RO plants is really lower than that one consumed by distillation plants (about 5 or 6 times, see Table 1) and consequently their derived CO_2 and NO_x emissions. Table 4 presents the airborne emissions provoked by different desalination technologies, revealing the gap between thermal and membrane techniques. These results have been obtained from a comparative Life Cycle Assessment (LCA), an environmental methodology which includes the entire life cycle of each technology, encompassing: extraction and processing raw materials, manufacturing, transportation and distribution, operation and final waste disposal, of most widespread commercial desalination technologies [22-24].

On the other hand, the effects on marine flora provoked by the RO brine disposal could be important in some places. For instance, in the case of the Mediterranean Sea and especially in the Spanish Levante, endemic specie called "Posidonia Oceanica" is strongly protected by the UE. It has been demonstrated that it is very sensitive to brine increments [25], and compensatory measures have to be taken by increasing the cost of the brine disposal system [26]. However, brine disposal from brackish waters, despite of its lower costs, could even degrade more and more the aquifer quality if it is not properly designed.

5.1. *Desalination vs. conventional fresh water provision solutions*

There are several regions in the Planet with enough fresh water resources in average but irregularly distributed, both geographically and along the time. This is the case of Spain, and some other Mediterranean countries, with water scarce areas created upon tourist or irrigation pressure. In this context, the next question arises: What is the best solution since an environmental view-point: conventional solutions based on the water conveyance from "wet" to "dry" regions, or new and innovative solutions mainly based on SWRO?

It is clear that each particular comparison will give to diverse results, but just as an illustration, is presented here a comparative LCA of the water transfer of 1,050 hm^3/y from the Ebro River (ERWT) to the Spanish coastal Mediterranean areas, and the production of the same amount of maximum diverted water applying the Reverse Osmosis (RO) desalination technology (further details can be found in [24]). The LCA analysis of ERWT presented in this paper is based on the basic documentation contained in the Transfer Project and its Environmental Impact Study [27,28] describing the proposed hydraulic infrastructures. In order to obtain as much as possible rigorous conclusions three different impact assessment methods have been applied (see table 5). SimaPro [29] is the software used to perform that complex LCA study, which includes the environmental loads associated to the construction and assembly of the installations, their operation and the final disposal once their useful life is finished.

The average energy consumption considered for the ERWT was 2.5 kWh/m^3 [24] in the operation phase of its life cycle, whereas RO consumed from 4 to 2 kWh/m^3, considering its decreasing trend of energy consumption. From results in Table 5 it can be concluded that with the present state of the art of both technologies, RO is slightly more pollutant than the ERWT. In both options, particularly in RO desalination as shown in Figure 6, the operation phase, in which the energy consumption is the most important factor, provokes the highest impact. Anyway, the weight of the ERWT construction is quite important with respect to the same phase for RO plants, a factor which is usually not considered for other environmental assessment techniques. The final disposal of both alternatives does not represent any significant contribution in any case.

Table 5. Overall LCA scores for different energy consumptions of RO and the Ebro River Water Transfer (25 and 50 years of amortization). [25].

	Unit	RO (4 kWh/m^3)	RO (3 kWh/m^3)	RO (2 kWh/m^3)	Transfer (50 years)	Transfer (25 years)
Eco-indicator 99	GPts	2.62	2.04	1.46	1.86	2.20
Ecopoints 97	GPts	43,400	34,200	25,100	29,900	35,900
CML 2 baseline	-	0.546	0.414	0.283	0.362	0.378

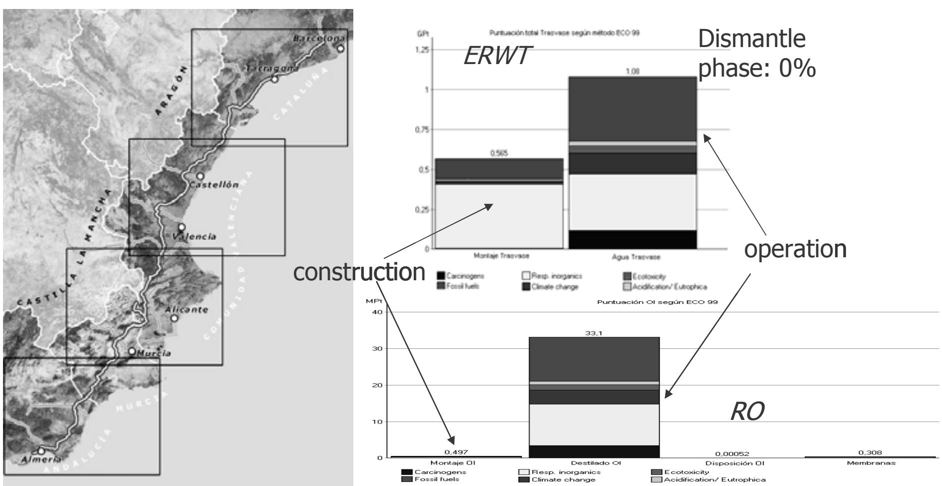

Figure 6. Map and LCA phase analysis of the Ebro River Water Transfer vs. the equivalent RO desalination production in Spain.

Although some minor impacts could not be evaluated by the LCA software (brine discharges in RO units, for instance), the global results present a very optimistic future for desalination (especially for RO) with respect to conventional hydraulic projects, since:

- Technologic improvements could reduce energy consumption, which is the most important environmental impact in the case of desalination. On the contrary, hydraulic projects are a mature technology.
- By integrating desalination with energy production systems, a very important reduction of the environmental charges of desalination could be obtained [30].

- Further, the gradual inclusion of renewable energies favors RO desalination more than conventional water supply techniques [24].

5.2. *Desalination integrated with different energy production systems*

Here, huge potential to reduce the impact provoked by desalination technologies, particularly distillation when integrated with diverse energy production systems. A detailed analysis can be found in [30].

Table 6. Airborne emissions considering different integration arrangements of thermal desalination and RO (4 kWh/m^3) with energy systems [33]: (TC: Thermal Consumption; CB: Conventional Boiler; CCC: Cogeneration Combined Cycle; DWH: Driven Waste Heat; SC: Steam Cycle; ICE: Internal Combustion Engine; CC: Combined Cycle; EM: European Model).

	Kg. CO_2/m^3 produced water	g. NO_x/m^3	g. NMVOC/m^3	g. SOx/m^3
MSF (TC-CB-EM)	23.41	28.30	8.20	28.01
MSF (CCC-EM)	9.41	10.88	3.13	11.34
MSF (DWH-EM)	1.98	4.46	1.27	14.96
MED (TC-EM)	18.05	21.43	6.10	26.31
MED (CCC-EM)	7.01	8.16	2.25	15.74
MED (DWH-EM)	1.19	2.53	0.62	19.59
RO (EM, 4 kWh/m3)	1.78	4.05	1.15	11.13
RO (SC)	2.79	3.38	0.93	3.25
RO (ICE)	2.13	2.61	0.65	2.86
RO (CC)	1.75	2.05	0.59	2.79

The results have shown in table 6 the importance, since an environmental viewpoint, of an appropriate water and energy systems integration. It shows the airborne emissions evaluated in the inventory phase of the LCA corresponding to diverse scenarios of integration for MSF, MED: from heat provided by a conventional boiler to a fully integrated one with residual heat, passing by combined cycle integration. Thus, the highest emissions correspond to the non-integrated case, decreasing as the efficiency of the overall system increases. Emissions associated to RO are significantly lower to those corresponding to thermal desalination but even an integration analysis can also be performed: as it was expected, there is a slightly, compared with thermal desalination, but non-negligible decrease in airborne emissions (up to 35%) when the energy production system is more efficient.

5.3. *Desalination driven by renewable energies*

The use of renewable energy systems (RES) for producing desalted water is not developed yet at a major scale, but it could be a very interesting solution for remote and lowly populated areas, where no other alternatives are available at affordable costs. The use of solar direct heating onto a glass surfaces collecting evaporated seawater only produces up to 4 l/m^2d; and the use of parabolic through collectors (PTC) concentrating the solar energy consumed in small MSF or MED units can improve that productivity up to 10 l/m^2d [31]. Photovoltaic solar cells connected to small RO units are quite affordable for isolated locations (see [32]) if a storage system and/or batteries are also included in the design project. But the most promising renewable energy for connecting RO desalting units is wind: the integration with pumping systems allowing the storage of water in small dams which produce power continuously for the RO unit with their associated waterfall, seems to be one of the promising future line for desalination in a low-medium scale (see [33] for the El Hierro Island experience).

Table 7. Airborne emissions for different integration arrangement of RO (EM: European Model; WE: Wind Energy; PE: Photovoltaic Energy; HPE: Hydro-power Energy; NM: Norwegian Model; S: Switzerland; SP: Spain).

	Kg. CO_2/m^3 produced water	**g. NO_x/m^3**	**g. NMVOC/m^3**	**g. SOx/m^3**
RO (EM, 4 kWh/m3)	1.78	4.05	1.15	11.13
RO (WE, 150 kW)	0.170	0.412	0.22	2.05
RO (WE, 2 MW)	0.117	0.429	0.079	1.80
RO (PE-S. 100 kWp)	0.900	2.105	0.726	7.809
RO (PE-SP, 100 kWp)	0.483	1.151	0.382	4.731
RO (PE-S, 500 kWp)	0,626	1.816	0.697	16.155
RO (PE-SP, 500 kWp)	0.347	1.005	0.368	8.904
RO (HPE)	0.082	0.24	0.05	1.68
RO (NM)	0.08	0.23	0.06	1.73

Table 7 shows the results of main emissions to atmosphere corresponding to the LCA for RO coupled with diverse RES, although the analysis has also been performed for distillers [34]. CO_2 emissions suffer the highest reduction, an average of 80%, and the SO_x emissions the lowest one, about 60%. The solar photovoltaic (PE) energy is the integration that provokes the highest emissions to atmosphere (about 55% of decrease). Hydro-power is the best integration, with a decrease about 92% in the airborne emissions, and wind power obtains medium results (about 75% of decrease).

Solar thermal technology was not considered in the analysis, but new developments would provide lower environmental loads than conventional PE panels:

- Direct Steam Generators (DSG) [35], by which it is possible to produce high-pressure, high-temperature steam (100 bar/400º C) directly in the absorber tubes of the PTC, and that can be applied to the production of electricity as well as to desalination processes [36,37]. The efficiency of this technology is about 15%.
- Solar power systems based on improving the Stirling engine [38]. The Solar Dish (SD) electric systems provide net solar-to-electric conversion efficiencies close to 30%, and consist of a solar concentrator, a cavity receiver, Stirling heat engine, and an electric generator located at the dish focus.

5.4. *Reducing environmental impacts*

To reduce the environmental impacts of desalination plants, starting from the present situation, some guidelines are suggested here:

- First, it is essential to reduce the energy consumption for all technologies, and integrate them with energy production systems, particularly with those driven by

RES. Provision of water but also energy, heat and cold is an efficient manner to reduce primary energy consumptions and therefore emissions [39,40].
- Reduce or even, impede the corrosion of materials, and use sound-insulation ones.
- Reduce chemical addition and use the less aggressive ones to the environment.
- Avoid (whenever possible) the use of chlorine by investigating new affordable disinfection methods, in order to prevent the formation of trihalomethanes [19].
- Reduce thermal contamination by immersing cooling exchangers in distillers.
- Increase the investment required for enlarging the brine discharge pipes, also for inland territories to collect saline waters from brackish plants.
- Finally, it would be highly desirable to apply the Environmental Impact Assessment (EIA) for new facilities, and specially strategic EIA for the cumulative impacts form several plants in one region [41].

6 Future Innovations

Several future research lines are open, some of them are presented here:

- The research oriented to the integration of water and energy systems, is essential to reduce the costs of water and energy in dual-purpose plants. Up to now, water and energy production were managed independently but a combined management and the appropriate tools as for instance Thermoeconomic Analysis [42] (permits an in-depth knowledge of both plants and their interactions) are the appropriated guidelines.
- The use of hybrid systems (RO + MSF/MED units), in which RO only operates under low power demand periods, usually in winter season for the Gulf Countries. Aquifer storage could also be combined in those periods [43].
- The use of experienced designers, consultants and operators, as soon as high qualified personnel and materials resistant to corrosion is also essential to increase plant availability, particularly for thermal plants [19].
- In the MSF process, UF/MF membranes increase their productivity since they avoid scaling in tubes [44]. And the required surface area for evaporators/condensers could be reduced in heat transfer is improved [19]. Even for low temperature operation in MED units, aluminums or plastic materials would be introduced.
- For membrane processes, one of the prominent lines is the search for a more simplified scheme in the pretreatment system. And RO membranes are yet susceptible for major improvements [45]: flow through membranes could be increased (or alternatively the pressure required to produce the same flow could be reduced). Specific costs of membranes should also be reduced (competency).
- The inclusion of ERS for large RO plants (pressure exchanger) substituting Pelton turbines could reduce up to 1 kWh/m^3 the specific energy consumption, reaching a total consumption (intake pumping + RO process + permeate pumping to storage system) of less than 3 kWh/m^3 nowadays [46].

All these measurements could reduce the costs of desalted water in the next future but not as recent decades: this is mainly due to the compensation produced by the expected increasing prices of energy, taking into account for the political situation and the environmental charges that will be associated to energy.

7 Closure

As it has been argued in this paper, desalination represents nowadays a reliable potable water supply with a great potential of technological improvement by means of improving its energy efficiency, through an appropriate integration, and therefore reducing their environmental load. It is particularly interesting for providing safe freshwater to big coastal cities. In some cases, desalination could be the dominant source for balancing water demands of a region (see [47]), but it should not as a general solution for everywhere. The reasons for that assumption are, among others, briefly explained here.

Integrated Water Resources Management (IWRM)

- Desalination should always be the last solution to avoid water availability problems: water "demand" strategies as efficient irrigation methods, reduction of losses in water networks, water saving devices in households, water markets in drought periods, and the intensive use of reused water should be strengthened previously. A paradigmatic example of that inadequate projection is Malta Island [41]: when leakage losses were reduced, desalination plants had overcapacity.
- Desalination should be the selected water "supply" alternative when it provokes less economic, environmental charges and climatic uncertainties than conventional alternatives for supplying water.

Costs

- At present, only 3% of global drinking water is supplied through desalination, but it is concentrated in developed countries and in the Arab Gulf countries (remember that 2.7 billion people live on less than 2 $ per day) [41].
- Costs have fallen to affordable levels for many communities (up to 0.5 €/m^3), but in the future they will continue to fall but not as fast as previously, since no major breakthroughs are envisaged in the immediate future.
- The use of desalted water for agriculture should be studied carefully: usually, the economic rationality of this solution is not justified, and the use of subsidies is quite extended. Moreover, in water scarce areas desalination for urban supply should not be applied to free up water for irrigation.

Environmental impact

- Desalination provokes local impacts but they can be mitigated, usually at low or moderate costs, which obviously must be charged to the users. And in most cases, they can be outweighed by the benefits.
- However, it has a serious global impact derived from its energy consumption. Remember that the thermodynamic limit for desalting seawater is about 0.8 kWh/m^3, i.e. the minimum realistic consumption for the complete plant would be estimated in 1.5 kWh/m^3, equivalent to a groundwater pumped out from a well at about 400 meters-depth. Therefore, seawater desalination will be always an energy intensive process and, as a consequence, it will not be the definite solution for water scarce areas till renewable energies would be massively introduced.

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REMOVAL OF CHLOROBENZENES FROM GROUNDWATER USING A COMBINED SOLAR PHOTOCATALYTIC/STRIPPING REACTOR

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Several decades ago serious contamination of the soil and groundwater occurred in Hidas, Hungary, due to the non-proper deposition of large amount of chlorobenzene wastes. To defend the drinking water basin of the area a depression method is used and the groundwater pumped up is purified by a UV oxidation lamp reactor, which operates at its full capacity. To make possible to increase the load on the lamp reactor, the development of a pre-purification system, a combined solar photocatalytic/stripping reactor has been developed on pilot plant scale for testing and optimization. The main features of this reactor are: (i) Daytime, in the presence of anatase-TiO_2 catalyst, it operates as a solar photocatalytic reactor utilizing the solar UV radiation for the mineralization of chlorbenzenes, (ii) The integrated stripper works day and night and serves for the removal of chlobenzenes by air purging. Air flows counter-currently with the water film, and chlorbenzenes removed by the air flow are oxidized in a catalytic air cleaning reactor, and (iii) Daytime the reactor functions also as a solar collector to heat water and thus, to accelerate the stripping process.

1 Introduction

Chlorobenzenes are persistent, poisoning, biologically non-degradable or hardly degradable materials. Their half-life in air is about one year, and their partly oxidized products like chlorophenols are extremely poisoning.

Two decades ago 16,000 tons of mixed poly-chlorobenzene waste, an industrial residue had been deposited in 72,000 metal barrels on open company fields first in Hidas, Cf., Figure 1, and then nearby Garé, Hungary. Due to the corrosion of the barrels, most of the waste (a solid material in winter and a viscous liquid in the summer period) leaked out, resulting in serious contamination of the soil and the groundwater.

Figure 1. Deposition of 72 000 barrels of mixed chlorobenzene waste.

To hinder the migration of contaminated water towards the drinking water basin of the areas, a "depression method" is used that means continuous pumping of groundwater from the contaminated area, Cf., Figure 2.

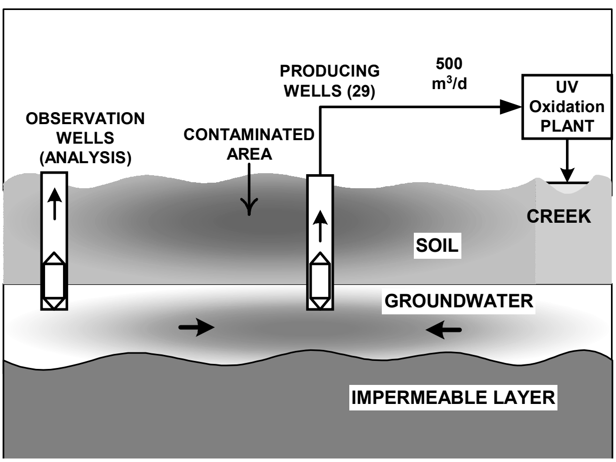

Figure 2. The scheme of the hydraulic depression method and the UV oxidation plant.

The water pumped up from the 29 wells presently contains about 0.1 - 1 mg/L impurity with a weighed average of about 0.2 mg/L. The impurity consists of isomers of di-, tri-, and tetrachlorobenzene isomers together with penta- and hexachlorobenzene. Contaminated water is purified to about 0.02 mg/L concentration in a 500 m^3/d capacity UV-oxidation lamp reactor, and then, by active carbon adsorbers to achieve the environmental limit of about 0.001 mg/L.

In spite of the continuous pumping, according to hydro geological research modeling the migration of impurities [1], there is an urgent need to increase both the number of pumps and the plant capacity [1]. To solve the problem on a most economic way, the development of a compatible, 1000 m^3/d capacity pre-purification system has been envisaged to make possible to increase the load on the present UV-oxidation reactor up to 1000 m^3/d. As a first step, the development of a combined, energy saving technology on 50 m^3/d scale has been started in 2004 [2]. Based upon our previous results [1], the new project applies solar photocatalytic oxidation, and parallel or alternatively to this, water purification by stripping.

2 Theoretical bases of the new technology

2.1. *UV oxidation of chlorobenzenes*

It is well known that the molecules can be activated not only by thermal treatment, but also by irradiation with photons, provided that the molecule is able to absorb the photon at the given wavelength. If the energy of the absorbed photon equals to or it is higher than the bond energy between the atoms, the molecule can dissociate to free atoms and radicals that have extremely high reactivity, and in the presence of oxidizing agents (O_2, H_2O_2, O_3, etc.) total mineralization of the molecule to CO_2 and HCl can be achieved. Chlorobenzenes are very stable molecules with high bond energies, Cf., Table 1.

Table 1. Bond energies and the corresponding photon wavelengths.

BOND	E_{DISS}, kJ/mol	E_{DISS}, eV	λ_{photon}, nm
Aromatic C-C	502	5.21	238
Aromatic C-H	461	4.78	259.1
Aromatic C-Cl	335	3.47	357
HO-OH	214	2.21	560

As mentioned, the rupture of a chemical bond occurs only if the molecule is able to absorb the photons of the given (or higher) photon energy. The UV adsorption bands of chlorobenzenes are narrow band structures in the region of 245-301 nm wavelengths [3]. Unfortunately, this region is practically absent in the terrestrial solar spectrum. (Due to the UV absorption by ozone layer, solar radiation colliding the Earth's surface contains only negligible amount of UV components below 300 nm, and nothing below 280 nm).

Therefore, efficient activation of chlorobenzenes occurs only by using deep UV range photons of the (mercury) lamp reactors. This is the reason why the rate of the oxidation of chlorobenzenes in the air is so slow, and their lifetime (half-life, $t_{1/2}$) is so long, it is in the range of one year. In the presence of appropriate catalysts, however, the rate of solar UV oxidation can be increased by a factor of several thousands. The process is called as *solar photocatalytic oxidation.*

2.2. *Solar photocatalytic oxidation of chlorobenzenes*

Metal oxides, mostly $SrTiO_3$ and TiO_2 have been used since a long time as photo-catalysts in photochemical synthesis, and for the destruction of biologically non-degradable contaminants. The advantages of the use of photocatalysts are:

- In lamp reactors they are able to utilize the near UV radiation of the lamps that otherwise can not initiate a reaction.
- They make possible solar water detoxification in such cases when the photon energy of the terrestrial UV radiation itself is insufficient to initiate a reaction.

<u>UV Photocatalysts</u>

Anatase-TiO_2 catalysts that have the highest photocatalytic detoxification efficiency are the most widely used ones. From these, high surface area catalysts very stable suspensions can be produced. To all probability, the most important application of TiO_2 catalysts is related to the oxidative mineralization of biologically non-degradable (hardly degradable) materials such as halogenated aliphatic and aromatic compounds in water [4-8].

The mechanism of photocatalysis is the following: TiO_2 is semiconductor with a wide band gap ($E_G \approx 3.2$ eV, referring to about 385 nm photon wavelength) between the valence band and the conduction band. Only light below 385 nm is absorbed and capable of forming a pair of e^- and h^+ hole on the catalyst. Then, since in water the surface of TiO_2 is hydrated, the h+ hole can react with hydroxyl ion, adsorbed water or hydrated proton, depending on the pH. In all cases an adsorbed OH-radical is formed, which is far more the strongest oxidation agent with the highest oxidation potential, and therefore, it is able to react with such persistent molecules like chlorobenzenes, PCBs, etc.

Summarizing the foregoing, with the use of TiO_2 catalysts, a great fraction of the terrestrial UV radiation can be utilized for water detoxification. Quite natural, the quantum efficiency depends also on the concentrations and the recombination rate of the e^- and h^+ pairs. In other words, in the presence of a photocatalysts a new reaction pathway opens, which is able to utilize solar UV radiation for the mineralization of high stability organic impurities.

<u>*The kinetics of the solar photocatalytic oxidation*</u>

Static systems. We consider that at constant UV radiation intensity and constant catalyst's concentration the reaction is closely first order in chlorobenzenes, since the concentration of the oxidizing agent (in our case dissolved oxygen) is in very large excess. The differential equation is:

$$- dC/dt \approx k_1 \, I_{UV} \, \Theta_{ChloroB}, \tag{1}$$

where are: k - the rate constant of the reaction; $\Theta_{ChloroB}$ - the surface coverage of TiO_2 by chlorobenzene, and I_{UV} - the solar UV radiation intensity.
At very low concentrations (in our case in the micromole/L range) the initial section of every adsorption isotherm is closely linear:

$$\Theta_{ChloroB} \approx \text{const. } C. \tag{2}$$

Introducing Eq. (2) into Eq. (1) we have:

$$- dC/dt \approx k_1 I_{UV} \text{ const. } C. \tag{3}$$

Integration with boundary conditions t = 0, C = C_o:

$$C \approx C_o\, e^{-k1\ IUV\ \text{const.}\ \mathbf{t}}. \tag{4}$$

Flow systems. In this case time t should be replaced by the residence time t_R, which is

$$t_R = V_{Water} / v_{water}. \tag{5}$$

Here v_{water} is the flow rate of water, and V_{Water} is the stationary volume of the 1 mm thick water layer present in the reactor. The concentration of chlorobenzene in the pre-purified water exiting the reactor is:

$$C_{out} \approx C_o\, e^{-k1\ IUV\ \text{const.}\ V_{Water} / v_{Water}}. \tag{6}$$

From Eq. (6) the pre-purification efficiency (conversion) $\varphi = (C_o - C_{out}) / C_o)$ is:

$$\varphi \approx 1 - \exp - (k_1 I_{UV} \text{ const } V_{Water} / v_{Water}). \tag{7}$$

It is seen that under fixed reaction conditions the <u>conversion is independent of the initial</u> concentration, which is a unique feature of the first order reactions. Naturally, in the case of mixed chlorobenzenes the case is not so simple, since the reactivity of the different components may differ significantly from each other. This difference, however, especially in the case of the main components of the contaminated groundwater is not so high, and therefore, both in closed and flow reactors in all cases closely first order kinetics has been obtained for the variation of the total chlorobenzene concentration with time or residence time.

2.3. *Removal of chlorobenzenes by stripping*

In spite of their low concentration and very low vapour pressure, chlorobenzenes easily evaporate from water. Their half-lifetime in water is in the range of several hours or days, depending on the depth and state (static, moving, stirred) of the water bed. The explanation is that chlorobenzenes form ***non-ideal*** solutions with water. As recognized earlier [1, 2], the equilibrium vapour pressure in aqueous solution is:

$$p_{Polychlorobenzene} = p^o_{Polychlorobenzene}\, c/c_{sat}. \tag{8}$$

It means that in saturated solutions the vapour pressure of chlorobenzenes Equals to that of the pure component, irrespective of the fact that the molar fraction of chlorobenzenes at saturation is far not unity, it is only 10^{-7} - 10^{-9}. In such cases the Equilibrium vapour pressure of the dissolved impurity will be 7 to 9 magnitudes higher than in the case of ideal solutions, which explains the easy evaporation of chlorobenzenes from water.

Static systems. The kinetic Equation of water purification in a static reactor is:

$$c = c^{o} \exp - [(\rho^{*} p^{o}) / c_{sat}] (\mathbf{v}_{Air} / \mathbf{V}_{Water}) \mathbf{t}. \tag{9}$$

where are: c - the concentration of the given chlorobenzene in mg/L; c_o - the initial concentration of the given chlorobenzene in mg/L; c_{sat} - the solubility of the given chlorobenzene in water in mg/L; ρ^* - the vapour density of the given chlorobenzene at T temperature and 1 Pa pressure; $\rho^* = 0.1203$ M/T in $g/m^3/Pa$ (M is the molecular weight in g/mol and T is the temperature of stripping in K); p^o - the vapour pressure of the given chlorobenzene in Pa at the temperature of stripping; $\mathbf{v}_{Air}$ - the flow rate of air in m^3/s; $\mathbf{V}_{Water}$ - the volume of the water in the stripping reactor in m^3 and **t** - the time of the stripping in s.

For kinetic calculations solubility data were collected from different handbooks. The temperature dependence of the vapour pressure of all chlorobenzenes was determined by extrapolation of the log P – 1/T diagrams that were created from literature data [9].

Stripping in flow reactor. The kinetic Equation for flow systems is obtained by replacing time t with the residence time t_R in Eq. (9). The residence time $t_R = V_{Water}/v_{water}$ as before:

$$C_{Out} = C_o \exp - [(\rho^{*} p^{o} / C_{Sat}) (\mathbf{v}_{Air} / \mathbf{v}_{water})]. \tag{10}$$

The conversion can be given as:

$$\boldsymbol{\varphi} = \mathbf{1} - \exp - [(\rho^{*} p^{o} / C_{Sat}) (\mathbf{v}_{Air} / \mathbf{v}_{water})]. \tag{11}$$

It is seen again that the conversion does not depend on the initial concentration.

3 Design and Construction

3.1. *The main directives of system design*

The criteria concerning the design of the solar photocatalytic reactor were:

- The system should utilize efficiently the solar UV radiation for the mineralization of chlorobenzenes in the presence of photocatalyst and oxidizing agent (O_2, H_2O_2, etc.).
- The system should be a closed one to avoid the escape of chlorobenzenes to air.
- The system should be supplied with a stripper that can operate day and night.
- Both in its solar photocatalytic and stripping reactor functions the reactor should be a continuous flow reactor.
- During stripping the water flow and air flow should be in counter-current.

- The reactor should be able to operate also as a solar collector to heat water by the visible and near IR radiation of the sun to accelerate the stripping process.
- The outlet air containing chlorobenzenes should be directed to an air purification system and purified air should be recycled to the stripping process.
- The system should be transportable on public road, to utilize it for future tasks on another spot.

Postulates

1. The targeted capacity of the pilot plant is 2 m^3/h.
2. The total concentration of chlorobenzenes coming from different wells is 0.1 < 1 mg/m^3, with a weighed average of about 0.2 mg/m^3. The main components are: Trichlorobenzenes (< 0.2 mg/L), Tetrachlorobenzenes (< 0.4 mg/L), Pentachlorobenzene (< 0.2 mg/L), Hexachlorobenzene (< 0.1 mg/L).
3. The temperature of water entering the reactor is 12 ^oC = 285 K, i.e., it equals to the temperature of groundwater.

Determination of the required air flow rate

Assume the case when thin layer of water flows counter-currently with air, and the equilibrium is almost perfectly achieved. Assume the partial pressure in the exiting air is only 80 % of the equilibrium value. Then it can be written:

$$p_{Polychlorobenzene} = 0.8\ p^o_{Polychlorobenzene}\ c/c_{sat}. \tag{12}$$

To determine the required air flow rate, assume the removal of pentachlorobenzene (one of the main components of the impurity with low vapour pressure) from water considering the least favourable conditions referring to winter season in the night: T = 285 K (12 ^oC), that equals to the temperature of groundwater; c_{PENTA} = 0.2 mg/kg, that is slightly higher than the average value. From literature data the solubility, $c_{PENTA,\ sat}$ = 0.83 mg/L. The vapour pressure extrapolated to 285 K: $p^o_{PENTA,\ 285\ K}$ = 0.27 Pa. From Eq. (3), its partial pressure in the exiting air $p_{PENTA,\ AIR\ OUT}$ = 0.052 Pa.

The vapour density of pentachlorobenzene at 285 K $\rho^*_{PENTA,\ 285\ K}$ = 0.0903 $g/m^3/Pa$, and its concentration in the exiting air $\mathbf{C}_{PENTA,\ AIR\ OUT}$ = 0.052 (Pa) x 0.0903 ($g/m^3/Pa$) = 0.0047 g/m^3**.** Since the targeted water flow is 2 m^3/h, the mass flow rate of pentachlorobenzene entering the stripper is 0.4 g/h. The removal of such amount of pentachlorobenzene requires an air flow of v_{AIR} = 0.4 g/h / 0.0047 g/m^3 = 85.1 m^3/h, which, with a margin of safety is v_{AIR} = 100 m^3/h.

Type of the photocatalytic/stripping reactor. A thin rectangular tray-type reactor with transparent glass glazing had been selected. This allows the use of high air flow rates, provides intense contact between the thin layer liquid and air. The cover exhibits the evaporation of chlorobenzenes to the atmosphere; it is transparent for solar radiation, including also, to a less extent, the UV radiation of the sun.

The transparent cover. The cover is a medium quality, 4 mm table glass fixed upon the tray. According to experiments, it withstands to pressure fluctuations occurring 100 m^3/h

air flow rate. Its UV transmittance in the terrestrial solar UV region as determined by spectrophotometer is shown in Figure 3.

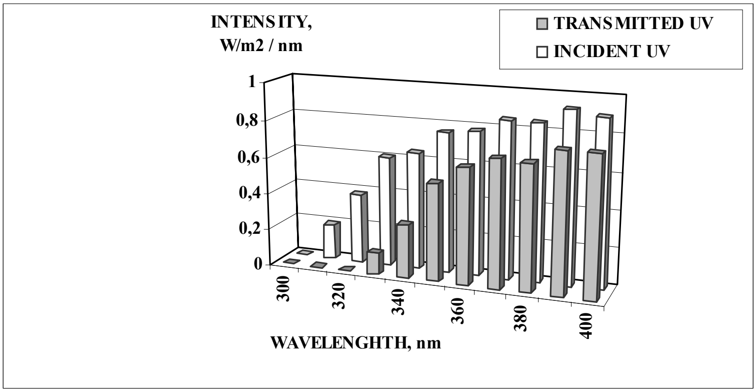

Figure 3. The smoothed terrestrial solar UV radiation (summer, peak hours) and its transmission through 4 mm glass pane.

In spite of the wide absorption band of the glass at 325 nm, below 385 nm about 60 % of the terrestrial solar UV radiation is transmitted by the glass cover.

Required photocatalytic reactor area. Based upon kinetic evaluation of our previous results obtained by a 4.5 m^2 area solar photocatalytic reactor [1,2], 32 m^2 reactor area has been chosen, since using such an area, in an average summer day about 2 m^3 water could be purified to the required level in one hour, without stripping. Considering that the usual size of the metal plates is 1m x 2m, four parallel units, each of 2m x 4m size and 8 m^2 area has been designed.

Rim of the trays. The tray's rim was designed as 0.02 m. With such a rim and at 100 m^3/h (0.0278 m^3/s) air flow rate the fluid-mechanical characteristics of the reactor are:

- The linear velocity of air, $v_{AIR,\ LIN}$ = 0.174 m/s, with no foam formation inside the tray.
- The Reynolds number, Re = D(e) v ρ / μ = 417, i.e., the flow is laminar.
- The friction coefficient λ_{Tray} = 64/Re = 0.153.
- Sum of the local resistances inside the tray $\Sigma\xi_{Tray} = 0$
- The pressure drop inside the trayΔP_{Tray} = 0.28 Pa, i.e., it is negligible.

For determining the Reynolds number ρ = 1.2 kg/m^3 air density and μ = 0.00002 Ns/m^2 viscosity was considered. The pressure drop is calculated for 4 m reactor length.

Reactor. The schematic diagram of one module of the reactor is shown in Figure 4. It is fixed onto a „self-carrying" metal frame, to make possible the transportation and easy installation of the ready modules. The weight of such a module with glass cover is 252 kg.

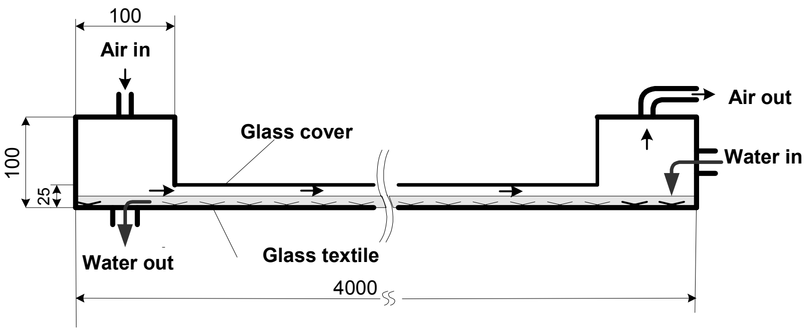

Figure 4. Scheme of one module of the integrated photocatalytic/stripping reactor.

In both ends the trays are supplied with 2 m long, 0.1 m wide and 0.1 m high chambers that serve for gas and liquid distribution and collection, Cf., Figure 1. The fluid mechanical features of air at reactor inlet and outlet are:

- Inlet tube diameter, D = 0.06 m.
- Cross sectional area in the tube, $A1 = 0.0028\ m^2$.
- Cross sectional area in the distributor, $A2 = 0.2\ m^2$.
- Linear velocity of air in the tube, $v_{Tube,\ lin} = 2.46$ m/s
- Reynolds number, $Re_{Tube} = D\ v\ \rho\ /\mu$, $Re_{Tube} = 8820$ (turbulent)
- Friction coefficient (from handbooks) $\lambda_{Tube} = 0.032$
- Local resistance due to sudden widening $\Sigma\xi = 0.5$
- Pressure drop due to sudden widening $\Delta P = 0.06$ Pa

Similar pressure drop appears at the reactor outlet. Altogether the pressure drop is marginal. It means that the integration of the reactor into the tubing system dos not effect the hydrodynamic properties of the system. Much care has to be devoted, however, to design the tubing, the catalytic oxidation reactor and the pump system to achieve closely atmospheric pressure inside the reactor during operation.

Operation of the reactor. The parallel units are moderately tilted towards the water exit. Water containing suspended TiO_2 is fed by variable speed water pump connected to the PC. Water is distributed in each unit and flows down by gravity, forming about one mm thick moving layer. From the reactor water flows by gravity to a collection tank and after micro filtering that serves for the removal of TiO_2 particles for reuse, it is pumped into the purified water tank.

The bottom of the tray is lined with a glass textile sheet. One of its functions is to distribute water inside the tray. Its other function is to fix TiO_2 particles that precipitated from water. Thus, the bottom of the reactor tray is always covered with TiO_2. Air is also distributed and flows counter-currently with water, to achieve the highest efficiency in stripping. Inside the reactor both the air flow and the water flow are laminar.

Solar collector function of the reactor. To decrease heat losses the reactor modules are back insulated with 5 mm thick plastic foam. Though the absorber (metal plate covered by TiO_2 in glass textile matrix and water layer) is far not ideal, detailed calculations supported by experimental data [2] have shown that the collector efficiency in winter and summer is 30 % and 70 %, respectively.

3.2. *Technological scheme of the pilot plant*

The technological scheme of the pilot plant is shown in Figure 5.

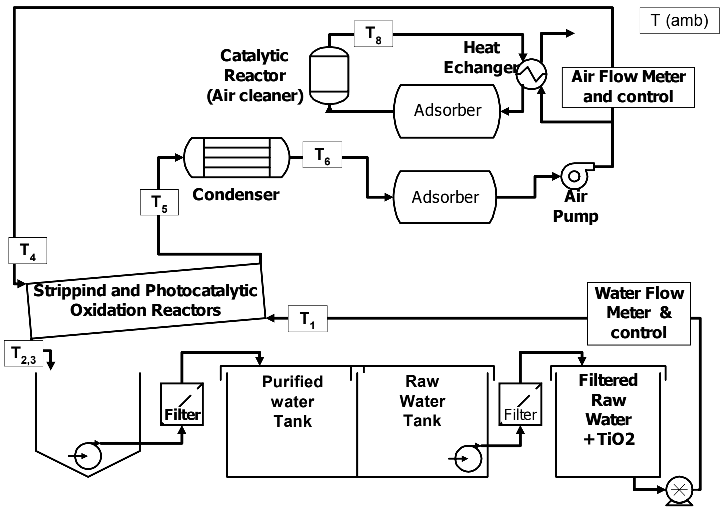

Figure 5. The flow sheet of the pilot plant of 2 m^3/d capacity.

<u>Water line</u>. From the raw water tank, with the use of a level-controlled pump, the raw water passes trough a micro filter to remove solid particles and enters the filtered raw water tank. Here, with the addition of TiO_2 and with permanent stirring a suspension is created. From this tank a controlled flow of the TiO_2-water suspension is pumped up and distributed to 4 Equal flows to feed the 4 reactors. In each reactor the suspension is distributed alongside the unit. In the reactors water is purified either by stripping or by catalytic photooxidation, or both. Purified water-TiO_2 suspension exiting the reactors flows by gravity into a tank. From here, with the use of a level-controlled pump, it is pumped through a micro filter to separate and recycle TiO_2 particles. The filtered water is lead into the purified water tank for analysis (and then, if the concentrations are below the limit, it is lead into a creek).

<u>Air line.</u> Air exiting the reactor enters a condenser where its excess water content is removed. Then, chlorobenzenes are captured in one of the two active carbon adsorbers and purified air is recycled for stripping. Parallel to this the other adsorber is regenerated with a much lower air flow at 300-320 ^oC, and chlorobenzenes swept by the hot air flow are oxidized in a catalytic oxidation reactor to CO_2, H_2O and HCl, and the effluent gas is

directed into the raw water tank where HCl is neutralized by hydro carbonates that are present in raw water in large excess.

3.3. *Construction and installation of the pilot plant*

The 4 modules of the reactor were designed and constructed by IMEC CRC HAS. Then, the modules were transported to the company field of Növ-Kör Co. Ltd. in Hidas. Installation of the pilot plant was designed and made by Növ-Kör Co. Ltd. Besides its 3 functions (photocatalysis, stripping and solar collector) the reactor got a further function: The roof of the pilot plant was constructed from the 4 trays, Cf., Figure 6. In the two „rooms" (each of 16 m^2 area) the additional machines and units (Catalytic air cleaner, Condenser, Adsorbers, Pumps, Flow meters, Liquid tanks, Filter systems, Data collection and process control system had been placed.

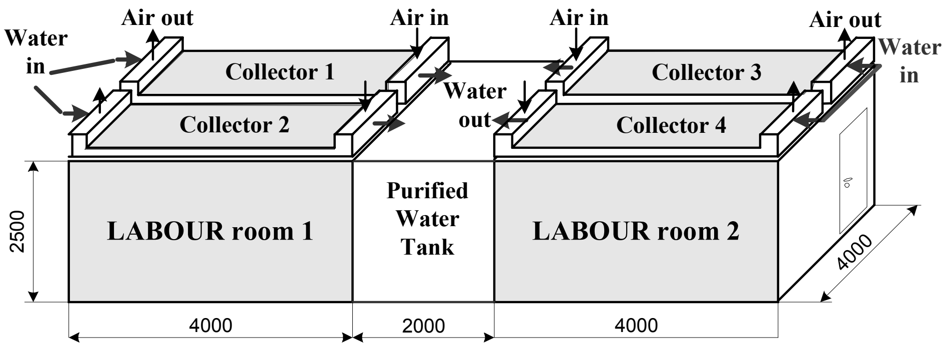

Figure 6. The schematic view of the pilot plant.

3.4. *Data acquisition, process control*

The pilot plant is supplied with a data acquisition and process control system. Fluid streams are monitored and controlled, the relevant temperatures, the solar radiation intensity, the solar UV radiation intensity are monitored.

3.5. *Determination of the required pre-purification level*

UV oxidation in the 500 m^3/d capacity lamp reactor is also (pseudo) first order in chlorobenzenes, since the water flow rate and the UV radiation intensity is constant and the concentration of the oxidizing agents (dissolved oxygen and H_2O_2 additive) is order(s) of magnitude higher than the oxygen demand of the photooxidation. Kinetic calculations have shown [2], that using raw water with the average, ≈200 microgram/L initial concentration, at least **66.5 %** pre-purification level is required for increasing the load to 1000 m^3/d without compromising the quality of the purified water, Cf., Table 2.

Table 2. Required pre-purification levels at different initial concentrations for 1000 m^3/h loading

Initial raw water concentration	Required concentration for 1000 m^3/h loading	Required pre-purification efficiency
300 μg/L	Max. 67 μg/L	Min. 77,6 %
250 μg/L	Max. 67 μg/L	Min. 73,2 %
200 μg/L*	**Max. 67 μg/L**	**Min. 66,5 %**
150 μg/L	Max. 67 μg/L	Min. 55,3 %

4 Results

4.1. *Trial of the system*

Using strongly contaminated water with 494 µg/litre total initial concentration, the first trial was made in a clear sunny day in 3 operational modes at $\mathbf{v}_{Water} = 2\ m^3/h$ loading:

- Purification by stripping ($\mathbf{v}_{Air} = 100\ m^3/h$, the mean reactor temperature $T_m = 285$ K).
- Purification only in solar photocatalytic operational mode (the global solar radiation $G = 670\ W/m^2$, the solar UV radiation $I_{UV} = 34\ W/m^2$, $T_{mean} = 291$ K, $TiO_2 = 1$ g/L).
- Purification by solar photocatalysis + stripping. ($\mathbf{v}_{Air} = 100\ m^3/h$, $G = 610\ W/m^2$, $I_{UV} = 28\ W/m^2$, $T_{mean} = 289$ K, catalyst = 1 g/L). The results are given in Table 3.

Table 3. Impurity concentrations in µg/litre before and after purification

MAIN COMPONENTS	In raw water	Case (a): after stripping	Case (b): after photocatalysis	Case (c): after photocatalysis + stripping
1,4- dichloroB	4.3	1.5	1.7	0.8
1,2,4-trichloroB	103	28	26	12
1,3,5-trichloroB	11	3,8	3.1	1.7
1,2,3,4-tetrachloroB	291	73	67	31
1,2,3,5-tetrachloroB	18	5.1	6.3	2.5
1,2,4,5-tetrachloroB	4.0	1.6	1.8	0.9
Pentachlorobenzene	63	19	17	7.6
Hexachlorobenzene	3.7	0.8	0.9	0.3
TOTAL	494	132.8	123.8	56.8
Pre-purification level	**0 %**	**73.2 %**	**74.9 %**	**88.5 %**

As Table 3 shows, in the first two cases the concentration of the pre-purified water could not be suppressed below 66.5 µg/litre total concentration, which is the main criterion for increasing the load on the existing lamp reactor. On the other hand, in all cases higher then than 66.5 % pre-purification level has been achieved, which is quite satisfactory in our case when the average concentration is only 200 microgram/litre, Cf. Table 2.

4.2. *Optimization of the system*

After the trial the work was focused on system optimization both in terms of system performance and economic feasibility. The most successful modification was the reconstruction of the water distribution to achieve complete and equable wetting of the reactor's bottom. Results obtained by the optimized system are shown in Figure 7 and Figure 8.

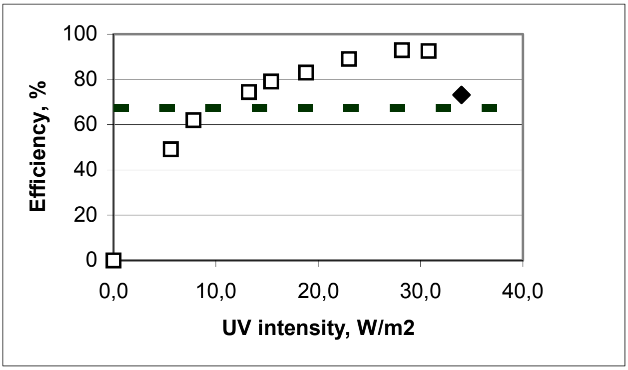

Figure 7. Solar photocatalytic oxidation of chlorobenzenes before (diamond) and after optimization (squares). Horizontal line is the required limit. (v_{WATER} = 2 m^3/h, v_{AIR} = 100 m^3/h, catalyst's concentration = 1 g/L).

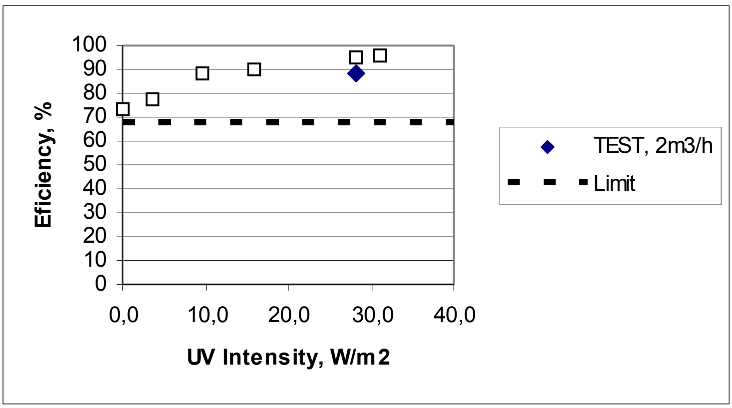

Figure 8. Solar photocatalytic oxidation combined with stripping. Diamond – test result before optimization, squares – after optimization. (v_{WATER} = 2 m^3/h, v_{AIR} = 100 m^3/h, catalyst's concentration = 1 g/L).

Based upon the results the technological plans of a scaled-up, 1000 m^3/d capacity pre-purification plant has been elaborated. Though the technology discussed above is energy saving and economic, the energy need of the pumps to filter off TiO_2 from its suspensions is not negligible. Now the work is focused on the development of such a system in which the catalyst is fixed upon the inner surface of the combined reactor.

Acknowledgments

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Nomenclature

C, c - the concentration of the given chlorobenzene, mg/L;
C_o, c_o - the initial concentration of the given chlorobenzene, mg/L;
C_{sat} - the solubility of the given chlorobenzene, mg/L;
D(e) - Equivalent diameter, m;
I_{UV} - the terrestrial solar UV radiation intensity on horizontal surface, W/m^2;
M - molecular weight of the given chlorobenzene, g/mol;
p - the partial pressure of the given chlorobenzene, Pa;
p^o - the vapour pressure of the given chlorobenzene in Pa at the temperature of stripping;
ΔP_{Tray} - the pressure drop inside the tray, Pa;
Re - the Reynolds number, -;
t - the time of the stripping or photocatalytic oxidation in static systems, s;
t_R - the residence time in flow systems, s;
T - the temperature of stripping, K;
$\mathbf{v}_{Air}$ - the flow rate of air, m^3/s;
$v_{Air,\ lin}$ - the linear velocity of air, m/s;
$\mathbf{v}_{water}$ - the flow rate of water, m^3/s;
$\mathbf{V}_{Water}$ - stationary volume of the water in the stripping reactor, m^3;
λ_{Tray} - the friction coefficient, -;
$\rho^* = 0.1203$ M/T, the vapour density of chlorobenzene at 1 Pa pressure, $g/m^3/Pa$;
$\Sigma\xi_{Tray}$ - the sum of the local resistances inside the tray, -;
$\Theta_{ChloroB}$ - the surface coverage of TiO_2 by chlorobenzenes, -;

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RELIABLE TRANSPORT OF SEWAGE WATER WITH CENTRIFUGAL PUMPS – ALL TECHNICAL PROBLEMS SOLVED?

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The supply of purified drinking water is indispensable in most inhabited areas of the earth and is therefore regarded in many areas as urgent task. In contrast, in many countries a central effluent disposal is realised only in closely inhabited areas so far. Since the emergence of waste water is extremely different in special regions such as cities, villages or rural areas, the collection and transport must be aligned to the special conditions. The hydraulic conveyance of waste water by centrifugal pumps provides some technical problems. Due the composition of the sewage water no conventional centrifugal pump can be used for the transportation of sewage water. The technical problems of the waste water transport by centrifugal pumps can be attributed predominantly to the pollution of the water and to the therefore necessary special pump geometry. Experience has shown, that pumps which are equipped with a single-blade impeller, show the smallest risk of clogging and still have relatively good efficiencies. However these pumps show the disadvantage that their operational behaviour is coined by enormous flow forces. These hydrodynamic forces provide high mechanical loads for the pump construction units (shaft, bearings, seals, etc.) and they are responsible for the transmission of vibrations to the environment. Beside clogging of the pumps, which can be caused by solids such as paper, textiles, wood, fibrous materials, sand of different granulation and particularly biologically degradable components, substantial vibrations as well as corrosion and abrasion effects are produced in sewage water pumps. In this contribution the problems arising during the conveyance of polluted water by centrifugal pumps are represented, analysed and paths to their solution are pointed out. Finally some examples for an ideal sewage water transport are discussed. For these examples the described technical problems in the field of pump technology are eliminated in the majority of cases. Thus the sewage transport, which is automated to a large extent is very reliable.

1 Introduction

A study of [1] shows that there is about 1.38 billions km^3 of water on the planet earth. But only 36 million km^3, which is about 2.6%, is sweet water and only 10% of this sweet water can be used as drinking water. The supply of purified drinking water therefore is indispensable in most inhabited areas of the earth and is therefore regarded in many areas as the most urgent task. In Europe the supply of drinking water is assured. In Figure 1 the usage of drinking water of several European countries is shown. The consume of drinking water in Europe is between 120 litres per resident (Belgium) and 260 litres per resident (Norway) for a day.

Because of the different use of water (personal hygiene, washing, flush, dish washing, and so on), with this water consumption the discharge of particular substances is aligned. So the drinking water becomes waste water, which has to be treated separately. The water, which has become waste water by the use of human beings can contain the an-organic ingredients and organic ingredients. A discharge of the waste water without purification leads to a distribution of harmful substances, which can already be inserted into the cycle of food. This is the reason that waste water must be processed and purified. The self-cleaning effect of watercourses (rivers, lakes, oceans) is limited because the decomposition of organic compounds by micro-organisms is limited by the oxygen content in the water. So waste water must be regarded as part of the elemental hydrologic cycle and could be treated as a renewable resource.

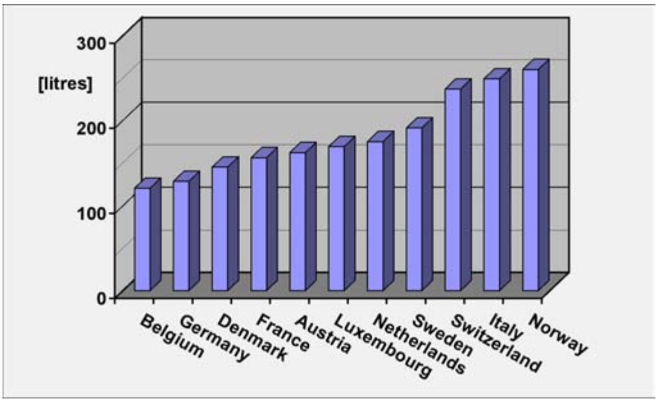
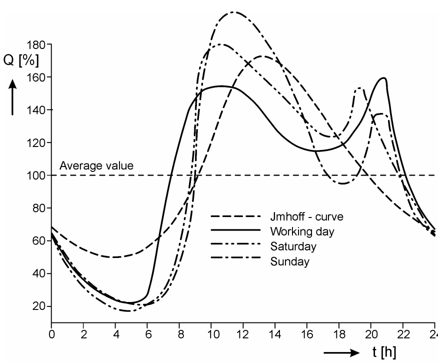


Figure 1. Usage of drinking water per resident and day for some European countries [1].

To purify the waste water it has to be transported from the location of its emergence (pollution) to the location, where it can be processed (purification). The total volume of waste water can be assembled from the following portions: domestic sewage, municipal waste water, agricultural sewage, industrial waste water, rainwater, infiltration water.

In Germany the amount of municipal waste water is about 25 million m^3 per day. After [2] the amount of waste water for different regions obviously is strong variable during the day. Figure 2 shows the amount of sewage water for a region, which is predominantly a residential area and a region which has a strong influence of industry. Both figures show that the variation from an average volume of waste water is very strong during the day and during the night.



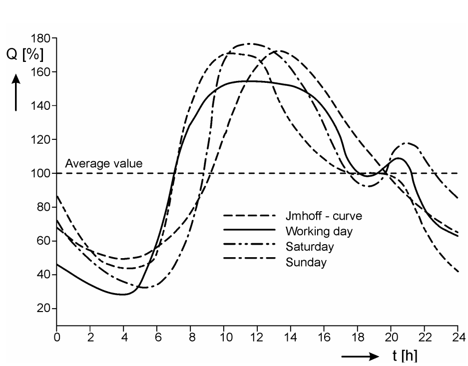


Figure 2. Emergence of sewage water: left diagram: residential area, right diagram: industrial area.

The transport of the sewage water to the location where it can be purified must be designed for all cases. Where it is possible due to the characteristics of the terrain the waste water can be transported by a sewer, which is open (at the surface) or closed (underground). There are several sewer systems which are used in different regions. One is the combined sewer system, where sewage water together with rainwater is transported. The second is the separate sewer system where sewage water and rainwater are transported by different systems. Very often the transport of waste water by downward slope is not feasible. For these cases other techniques must be established. As an example the waste water transport by a pressure line can be mentioned. In this cases the sewage water is transported by pumps through pipes. Finally sewage water must be transported by pumps, to bring it to a treatment plant.

In ancient times waste water has already been conveyed through a canalisation. Sewer systems are known from the 6th millennium before Christ from Turkey. In the 5th century Anno Domini sewage water systems have been built in Rome. When the industrialisation leads to a strong rise of urban population, the problems concerning the hygiene and disposal of excrements increased. The invention of the water closet had also a strong influence on the emergence of sewage water. So the construction of sewage water systems started again in the 19th century, because of some cases of epidemic.

In the last 150 years the waste water treatment developed from chemical treatment to the mechanical biological treatment. In Figure 3 the sources of sewage water are shown for a residential area. About 28% of all waste water is domestic sewage. Nearly 60% comes from rainwater and about 10% from industry. The whole waste water is collected by a canalisation and conveyed to a treatment plant. After purification the water can be given back to the natural cycle. Already today most of the waste water throughout the world stays untreated and is guided without purification into rivers, lakes and oceans. Only a small part of it is purified until now. The amount of purification differs very strong from region to region. In Germany one can assume a nearly complete treatment of all incidental waste water (about 85 % biological treatment). In contrast, in many countries a complete waste water treatment is realised only in closely inhabited areas. In the next decade in other countries of the European Union a fundamental step will be done to a substantial treatment of the waste water. Poland for example is planning the installation of 980 water treatment stations up to the year 2015. In other non-European countries the treatment of waste water is only at the beginning. In China for example only about 10% of the incident sewage water is purified at this time (preferably in the cities). In Africa the portion of waste water which is conveyed to a treatment is yet noticeable smaller. Since the emergence of effluent is extremely different in special regions such as towns, villages or rural areas, the collection and transport must be aligned to the special conditions. Anyway a sustainable waste water management should include the treatment of all waste water. A substantial reason for the only partial collection and treatment of waste water is definitely the transport of the raw sewage water, which is much more complex compared to the transport of purified water. The hydraulic conveyance of waste water by centrifugal pumps provides substantially larger technical problems. Due to its composition, which represents frequently a mixture from domestic sewage water, industrial waste water, local waste water and water, which is drained off from the surface during rain, no conventional centrifugal pump can be used for the transportation of sewage water. Only pumps, whose lay out and design is particularly aligned with the conveyance of raw sewage water, are suitable for a trouble-free automated sewage transport.

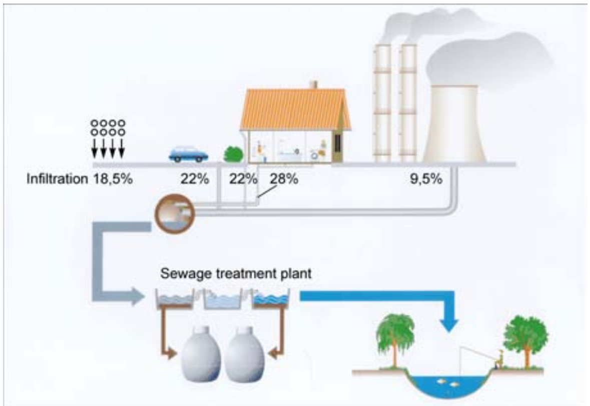
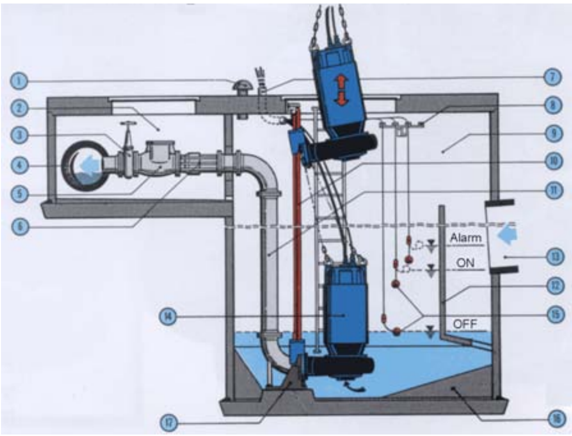


Figure 3. Way of the water.

This paper is addressed to the technical problems which are associated to the transport of sewage water with centrifugal pumps. The technical problems of the waste water transport by centrifugal pumps can be attributed predominantly to the pollution of the water. Some of the problems arising during the conveyance of polluted water by centrifugal pumps are discussed, analysed and paths to their solution are pointed out. Finally some examples for an ideal sewage water transport are discussed. Additionally some applications are shown, which contain also different sewage transport concepts. For these examples the described technical problems in the field of pump technology have been eliminated in the majority of cases. Thus the sewage transport, which is automated to a large extent is very reliable.

2 Waste Water Pumping Stations

The waste water which has been collected by a sewer system finally reaches a pump sump. This sump is part of a pumping station from which the waste water is transported to the sewage treatment plant. Normally pumps of different sizes are installed in a pumping station to allow the operating company to follow the sewage water emergence by switching pumps on and off as the need arises. By this method a redundant operating method is also ensured. Pumps can be installed in two different ways: one is the wet installation, where a submersible pump is installed in the pump sump. An example for this kind of installation can be seen in Figure 4.a.



1 Ventilation
2 Fitting slot
3 gate valve
4 drain path
5 non-return valve
6 shifting
7 cable protection
8 mount for liquid level switch
9 collecting sewer
10 guide tube
11 discharge pipe
12 inflow chamber
13 inlet pipe
14 submersible pump
15 level switch
16 concrete pump sump
17 pump base

Figure 4.a. Wet installation of a sewage water pump [3].

In this case the pump is installed in vertical arrangement. That means the shaft of the pump impeller and of the electric submersible motor is in vertical direction. Figure 4.b in contrary shows a dry installation of a sewage water pump. The shaft of the pump impeller is in horizontal direction and the pump is driven from the electric motor by a belt. The installation room of the pump is separated from the pump sump and the pump is sucking in the flow by an intake manifold which goes through the wall into the pump sump. The building for a pumping station with dry installed pumps is somewhat more expensive than for a pumping station with wet installed pumps but it has the advantage that the room for the pumps is clean and the pumps can be inspected by the field service personnel every time. For this kind of pump installation several designs of centrifugal pumps have been realised in the past.

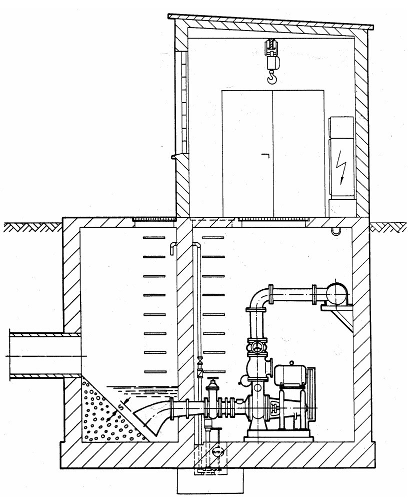


Figure 4.b. Dry installation of a sewage water pump.

Figure 5 gives an overview of the most common types of construction. The bloc pump is directly coupled to the electric drive and the impeller is mounted at the shaft of the motor. This kind of pump type can be installed both in vertical and in horizontal direction. Its design is very compact and saves a lot of room in the building. The next example shows a pump which is coupled to the electric drive by a clutch. This kind of pump arrangement can also be installed horizontal and vertical but takes more room than the bloc pump. The third and last example of the direct driven pumps shows a pump which is driven by a power train. Not direct powered pumps can be driven by belts, chains or gears. For more information see reference [4].

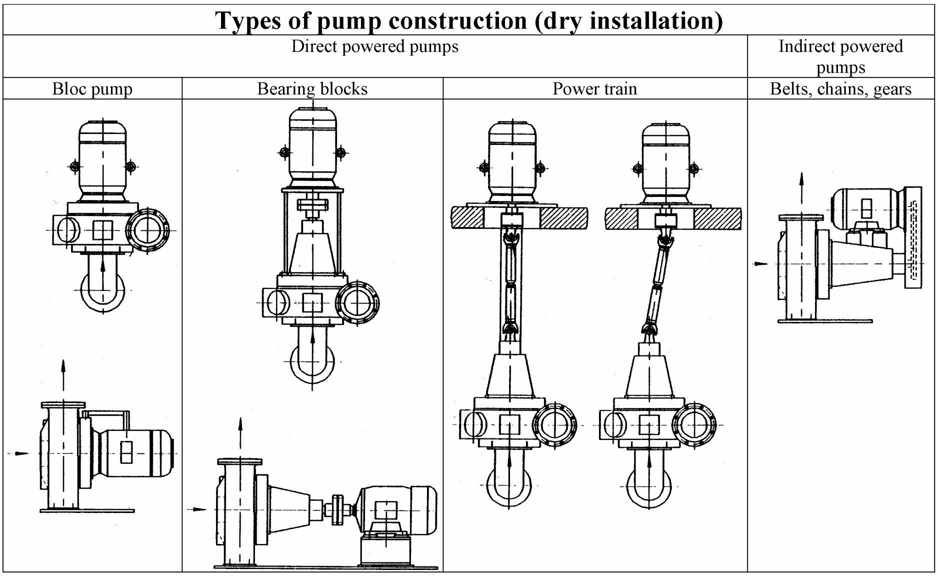


Figure 5. Different design of sewage water pumps.

Figure 6 shows a view into a pumping station with a couple of dry installed pumps. Only two of the total number of pumps are shown. Both pumps are direct coupled bloc pumps and the larger one (DN 400) is arranged vertical while the smaller one (DN 150) is arranged horizontal. So the available space can be used very economical.

3 Special Design of Pumps for Transport of Sewage Water

As has been explained in the introduction chapter, waste water can be composed from different sources. Normally several components are mixed to clean water: mechanical pollution like slurry, sand of different granulation, paper, textiles, wood, fibrous materials and biologically degradable components. All of these components can cause clogging of the pumps. To decrease the risk of clogging, a special design is necessary for a pump which is selected for the transport of sewage water. In Figure 4.b a gap of width s is shown at the suction mouth of the pump. All solids which are sucked in at this intake should be delivered by the pump without clogging. This requirement demands a special impeller geometry. To choose the optimal impeller geometry, in Figure 7 all emerging fluids which contain strong parts of water are divided into four classes of pollution [4].

Figure 6. View into a pumping station [5].

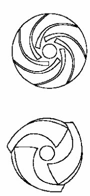
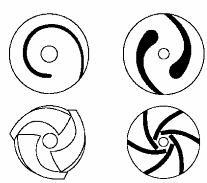
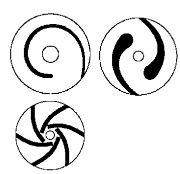
	Pollution of water					
	Drinking water	**Process water**	**Waste water**			**Slurry**
	No pollution	Lightly polluted, mechanical treated	Abrasive polluted	Raw waste water	Water containing fibers and solids	High portion of solids
Description	Domestic fresh water	Rainwater, service water, showerwater, cooling water, sea water	Water from excavations, concrete slurry	Domestic sewage, excrements, rainwater, industrial water, municipal waste water	Domestic sewage, industrial water, municipal waste water	Fresh slurry, digested sludge, circulating sludge, activated sludge
Occurrence	Municipal water supply	Mining, farming, horticulture, iron and steel industry, textile industry, dyeing factory, irrigation, offshore technique	Construction industry, mining, sewage technology	Municipal effluent disposal, domestic de-watering, pressure flow systems, sewage water pumping stations, sewage water lifting systems, agricultural effluent disposal	slaughterhouse tannery paper industry	Waste water treatment stations
Impeller design						

Figure 7. Classification of water by the degree of pollution.

The cleanest water we can imagine is the drinking water. This water is without any pollution and can be conveyed by any normal pump impeller, which has a certain number of blades. The next category is process water, which is lightly polluted but mechanical treated. This water can also be pumped by normal pump impellers, but sometimes impellers with small numbers of blades are used. For the third and the fourth category, which contain all the waste water with a considerable amount of solids, no impellers with more than 3 blades should be used. Especially for the raw sewage water, like domestic sewage, municipal sewage or industrial sewage, impellers with very small blade numbers should be used. With decreasing blade number the risk of clogging reduces tremendously, but can not be avoided at all.

Every existing leading edge of an impeller blade can collect fibrous material like textiles, paper and so forth. As the minimum blade number is one, normally pumps with a single blade impeller show the smallest trend for collecting fibres and they can also transport the largest solids due to the large flow path, which is built by the impeller and the casing. Experience has shown, that pumps which are equipped with a single-blade impeller, show the smallest risk of clogging and still have relative good efficiencies. However these pumps show the disadvantage that their operational behaviour is coined by enormous flow forces. These hydrodynamic forces provide high mechanical loads for all pump construction units (shaft, bearings, seals, etc.) and they are responsible for the transmission of vibrations to the environment. This often leads to a pump failure or to damages at the attached pipes or other equipment.

The choice of the right impeller for a sewage water pump is not very easy because of the composition of the sewage water, which sometimes is not known. So all manufacturers prepare their sewage water pumps to be equipped with different impellers. Figure 8 shows a section throughout a sewage water pump which can be provided with a single-blade impeller, a double-blade impeller and a free flow impeller. For pumps of bigger sizes normally also three bladed impellers can be used.

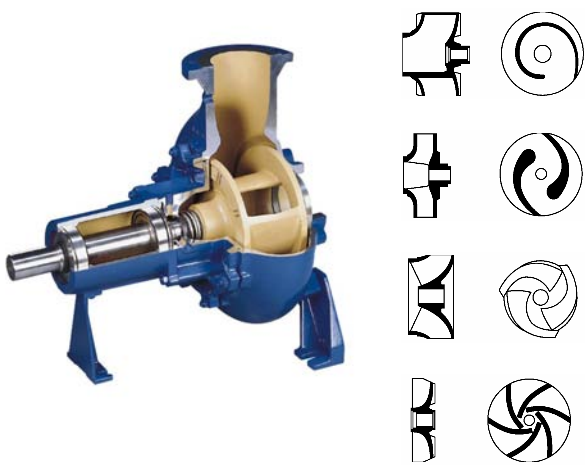


Figure 8. Single stage sewage water pump for different impellers [6].

4 Technical Problems of Pumps for Sewage Water Transport

4.1. *Clogging of Pumps*

The use of sewage water pumps with their special design, can avoid some of the problems which appear during operation. First of all the transport of raw sewage water covers a big risk of clogging. In Figure 9.a a view through the suction pipe into the mouth of an impeller is shown. This pump is completely clogged by papers, textiles and some other fibrous material. If this happens the pump does not deliver fluid anymore and must be shut down for safety. The system must be opened and cleaned manually. This kind of work is very nauseating and can lead to conveyance of divers diseases. Such clogging can not be avoided in full but the choice of the right impeller will strongly decrease the risk of clogging. So the reliability of all impellers can be classified by a so called “free ball passage”. That means, a solid which has the shape of a sphere with a certain diameter must be transported by the impeller without clogging. In Figure 9.b this situation is shown for a 3 bladed pump impeller. During the development process of a sewage pump a big free ball passage must be achieved by optimising the design of the impeller and the casing.

Figure 9.a. Clogged sewage pump [7].

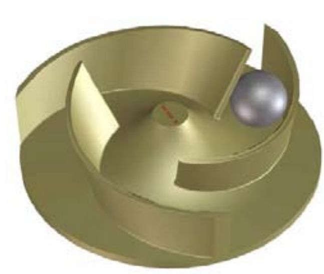


Figure 9.b. Free ball passage of a 3 bladed impeller.

4.2. *Vibration and Mechanical Stress*

Generally the largest free ball passages can be obtained for single-blade impellers. Due to their uneven distribution of mass around the circumference, which gives a strong mechanical unbalance, those impellers can only be utilised up to a certain size. Beside the mechanical unbalance, which gives a constant centrifugal force enormous hydrodynamic forces appear during operation because of the also uneven pressure distribution around the blade. As the hydrodynamic forces are not constant during the impeller revolution they can not be balanced by attaching of a balancing weight. These forces lead to a strong stimulation of vibrations which gives high mechanical stress for the pump construction units like shaft, bearings, seals, and so on.

In Figure 10 a statistical data collection of measured vibration velocities for sewage pumps of different sizes is presented. To avoid mechanical problems the vibration behaviour of the pumps are evaluated by [8]. With this valuation standard only very few pumps are in the range of "o.k." Most of them we can find in the range "usable" but a lot of pumps can not be accepted because of too strong vibrations, which can cause severe damages at the pump or at attached pipes. This figure shows that vibrations of sewage pumps is a severe problem, which is already under investigation [9,10].

In Figure 11 measurements of static pressure in the casing of a single-blade pump are shown for several operating points at nominal speed of rotation. For shut down condition the highest pressure level can be recognised. With increasing volume flow rate the pressure level is strongly decreasing. The pressure difference between maximum and minimum pressure for one impeller revolution is about one bar for the shut down condition. With increasing flow rate the pressure difference is decreasing and reaches a value of $\Delta p \approx 0{,}5$ bar at the maximum flow rate. The pressure distribution around the impeller is acting at the impeller surface during operation and leads to a recurrent stress. The result is a strong bending of the rotor shaft, which gives a deflection of the impeller. This impeller deflection has been measured by [11]. In Figure 12 the measured orbit curves of the single-blade sewage water pump are presented for the design speed of rotation. As the attacking angle of the hydrodynamic forces varies only little during one impeller revolution [12], the exciting forces rotate with the impeller. Depending on the change in magnitude of the forces during one impeller revolution the orbit curves become nearly circular or elliptic.

With increasing impeller turning angle the rotor orbit curves rotate counter-clockwise. The impeller is also rotating in counter-clockwise direction. So the rotation of the shaft orbit corresponds to the orbit rotation. Measurements at smaller speeds of rotation show smaller impeller deflections. The results show that for all speeds of rotation the deflections increase with increasing volume flow rate. The largest deflections have been measured for the highest and the smallest deflections for the lowest speed of rotation.

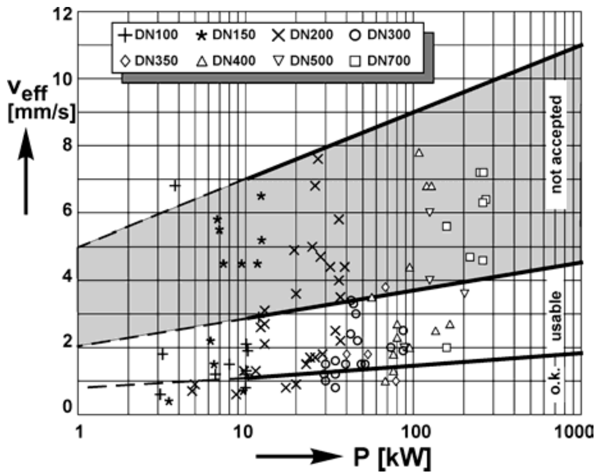


Figure 10. Statistical evaluation of vibration measurements.

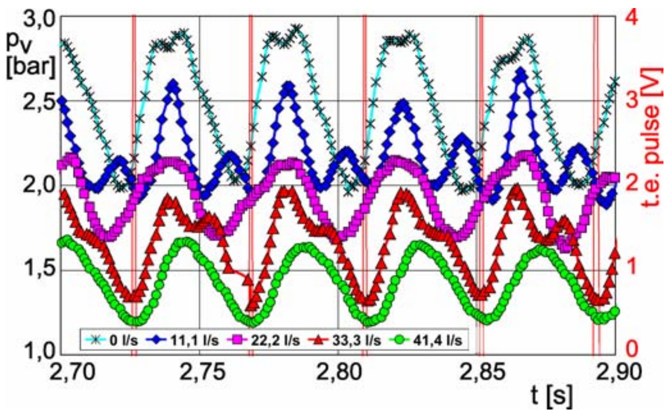


Figure 11. Measured static pressure inside the pump casing.

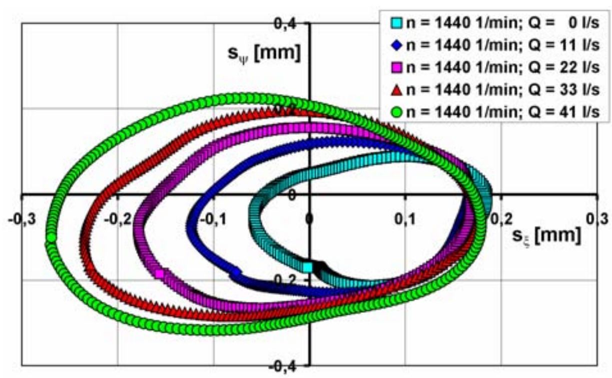


Figure 12. Measured rotor orbit curves of a single-blade pump.

Beside the oscillations of the rotor the exciting hydrodynamic forces generate also structural vibrations of the pump. The effects of the stimulating forces can be shown very clear by measuring the vibration properties at the outside of the pump casing. Therefore measurements of the vibration accelerations in radial and in axial direction were accomplished at the same time. In Figures 13.a,b the frequency spectra obtained by Fast Fourier Transformation are shown for several flow rates at nominal speed of rotation. All amplitude spectra show the first significant amplitude at the rotor turning frequency (≈ 24 Hz). The next strong amplitude appears at a frequency twice the rotor turning frequency. At the third mode the amplitudes are considerably smaller but anyway noticeable. No significant frequencies appear beyond the frequency of the 3rd mode.

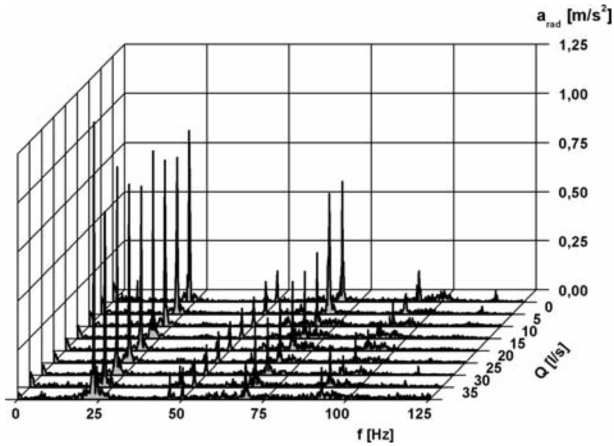


Figure 13.a. Frequency spectra of radial accelerations (n = 1440 min^{-1}).

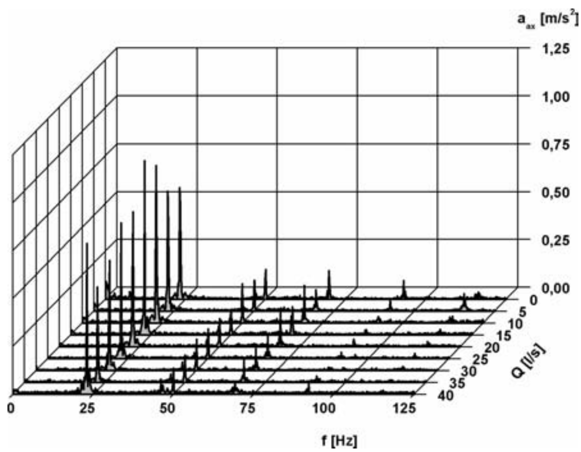


Figure 13.b. Frequency spectra of axial accelerations (n = 1440 min^{-1}).

4.3. *Materials of Pump Components*

To prevent the abrasion and corrosion effects of waste water special materials for construction of impellers and casings are required. For neutral waste water (pH-values > 6,5) like municipal sewage water or rainwater normally grey cast iron (GG-25) is used. For highly abrasive fluids which contain a strong portion of sand and solids a wear-resistant white iron (NORIHARD®) can be used. The material belongs to the so-called white iron alloy group and its hardness and wear resistant properties come close to those of pure metallic oxides, metal carbides (hard metals) and hard-plating materials. Table 1 shows some properties of materials which are often used for construction of pump components. If the pump is provided for transport of chemical aggressive sewage water a cast ferritic-austenitic stainless steel (NORIDUR®) is a good choice. This material exhibits a very good resistance to uniform corrosion in a wide range of acidic media of all kinds. Also the combination of stainless steel and synthetic material can be used for pumps which have to resist chemicals and should not rust. The hydraulic components are made of high grade synthetic material moulded into shape so that no machining is required.

Table 1: Features of some materials for pump construction

Application	Material data	Features
Neutral sewage water sand<1g/l; pH>6,5	Grey cast iron, GG-25	Cost-efficient, acceptable lifetime
Sewage treatment (effluent with high sand content)	NORIHARD® G-X 250 CrMo 15 3	Wear resistant, small abrasion rates during tests
Chemical aggressive effluent (pH=1…12)	NORIDUR® G-X 3 CrNiMoCu 24 6	Resistance to corrosion reducing acids and to localised corrosion attack
All sewage water	Baydur®GS, Polyurethane	High impact strength and chem. durability

5 Examples for a Reliable Sewage Water Transport

A sustainable effluent disposal should include the treatment of all waste water. Nowadays in Germany the waste water treatment has reached a very good estate. In Figure 14 the development of public sewage water processing is shown for the last 50 years. In the year 1957 only 40% of all sewage water has been treated mechanical or biological and 60% stayed already untreated. In the next 35 years the method of biological treatment increased up to about 90% in the old countries of Germany. In the year 1991 a first statistical evaluation of the new countries showed that there existed a sewage water treatment of only 57% (mechanical and biological). That means for the combined old and new countries a waste water processing of only 85% which again increased up to now to more than 90%. Only for about 3,5% of all effluent there is no purification. In the following two examples of an exemplary sewage water management will be discussed. The first is a small island which is located in the new countries of Germany and the second is a big industrial region in the old countries.

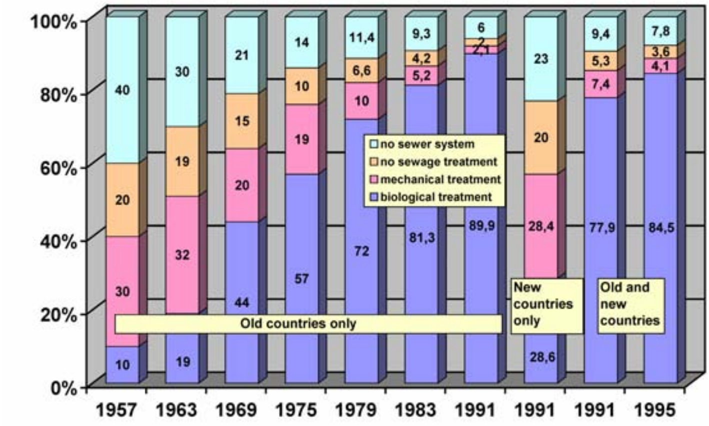


Figure 14. Development of public waste water treatment in Germany [13].

5.1. *Pressure Flow Sewer System for a Small Island*

A good example of a reliable sewage water transport can be shown for a small German island, which is named Hiddensee and which is located in the Baltic sea near the famous island Rügen. Figure 15 shows a map of the island which is very small and the settlement is scattered into four different communities. It has an area of about 18,6 km^2 and due to a lot of tourism the meanwhile completed solution with one central treatment plant has been designed for large seasonal variability of inflow. The most important data of the treatment plant and the water collecting system are shown in Table 2.

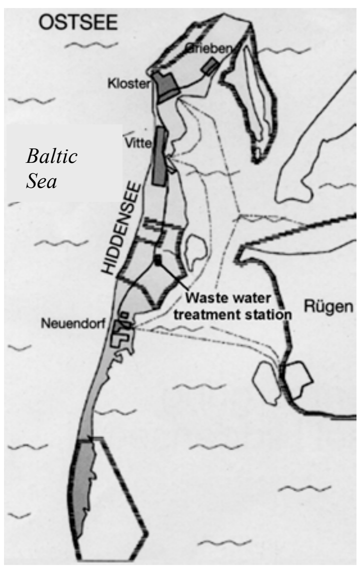


Figure 15. German Baltic Sea Island Hiddensee.

Table 2. Data of Hiddensee treatment plant and pressure flow system [14].

Treatment plant	
Capacity	7000 EW
Max. water amount	720 m^3/d or 72 m^3/h
Pressure flow system	
Degree of connection	100 %
City pipelines	23,3 km
Transmission pipeline	6,4 km
pumping stations	347
Main pumping stations	3

The island is very flat and the terrain has no downward slope, hence a sustainable sewage water collection makes only sense, when the water is transported by pressure pipes. So the waste water is collected in every community with a pressure flow system. In sum about 350 waste water pumping stations have been installed. The complete underground piping system, which has a cumulative length of 30 km was manufactured of thermoplastic material (HPDE). Figure 16 shows an example for a pressure flow system of a single building and the complete network of pressure pipes for a community. To overcome the attitude between the domestic sewage system and the main pressure line centrifugal pumps are used.

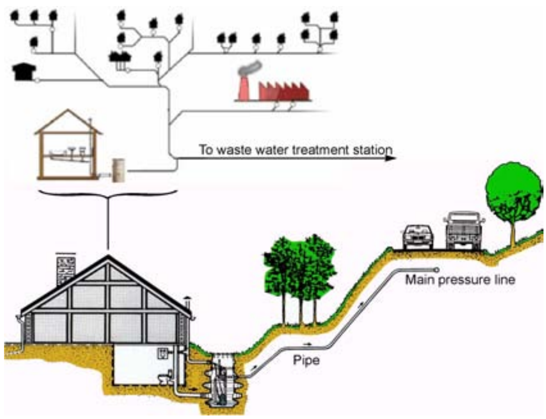


Figure 16. Pressure flow system for waste water.

5.2. *Closely Inhabited Industrial Area*

The second example is shown for a region in the middle west of Germany. In the mid of the 19th century the region east of the river Rhine, between Dortmund and Duisburg was only sparsely populated. Beginning at about 1850 a strong industrialisation commenced.

Beside the establishment of the heavy industry a considerable mining of mineral coal has been practised. Due to the extensive subsidence caused by this mining polder areas arose which had no elemental drain. In these sinks the surface water and the effluent of communities, mines and industry was collected. The river Emscher and a lot of small feeders lost their elemental outflow by mining. As this problem of de-watering only could be treated sustained from the affected region jointly, in the year 1899 the companionship Emschergenossenschaft has been founded from the communities, the industry and the mining companies.

First of all the river Emscher was straightened, deepened, banked and where the topological circumstances could not provide the necessary downward slope for the drain, pumping stations were built up to convey the waste water from lower territories into the river Emscher. At present the Emschergenossenschaft is operating 137 pumping stations which have a cumulative volume flow of 645 m^3/s and an electrical connected load of 133 MW. In Figure 17 the whole territory is presented with all its pumping stations. In this manner the river Emscher and its feeders have been used for a long time as an open sewer system. Because of the strong subsidence caused by mining there was no chance to construct underground canals. This river and all its feeders has been polluted in this way and animals had nearly no chance to survive. When the pollution of the river Rhine achieved also a critical amount, the companionship Emschergenossenschaft started a biological treatment of all water which was transported by the Emscher. From 1965 to 1997 several sewage treatment plants were built up along the river Emscher, which purify all the effluent emerging from the complete territory. The treatment plant Emschermündung, which has a design capacity of 5 million EW is the biggest one. This treatment plant is purifying all the water of the Emscher river before it is conveyed into the Rhine.

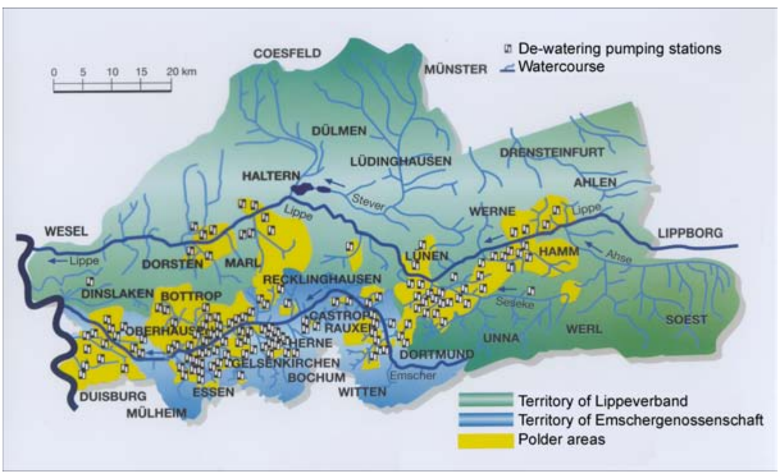


Figure 17. Installed pumping stations in the Emscher region [1].

For a fairly long time people are trying to reverse the process described above and to rebuild the river and its vicinity. As the mining moved north no more subsidence must be expected in the Emscher territory which now makes underground sewers feasible without worrying about breaking of pipelines. The rebuilding of the Emscher river territory will take place in the following manner: From the spring to the river mouth subterranean canals will be passed parallel to the river and its feeders and the waste water will be conveyed from the old river bed into the new channels. The new underground canal is going to grab all the effluent which has been conveyed into the river Emscher before. The construction started already in 2002 and will be finished in 2014. Therewith a unique effluent disposal system will be created, which comprises an area of about 865 km^2 with about 2,5 million residents. In Table 3 the most important data of the Emscher-canal which will carry the sewage water and the rainwater of the cities Bochum, Herne, Gelsenkirchen, Essen, Bottrop, Oberhausen and their surrounding area are presented.

Table 3. Important data of the new Emscher-canal.

Emscher - canal	
Length	55 km
Attitude	Up to 40 m
Maximum pipe diameter	3,8 m
Planned completion	2014
Expenses for the canal	2,0 billions of Euro
Investment for the project Emscher-rebuilding	4,4 billions of Euro

This sewer will be constructed in several sections. Due to its attitude it requires a considerable amount of pumping stations to overcome the attitude differences and to give the sewage water the required downward slope. The locations of the three already operating waste water treatment plants are shown in Figure 18.

Figure 18. Waste water treatment plants at the river Emscher [15].

6 Conclusions

During the past decades the aiming at high technical reliability, economical design and cost-saving operation of waste water pumping stations motivated both manufacturers and owners of pumping stations to realise new findings for the construction and the technical equipment of pumping stations. Basic design features for optimum planning of sewage water pumping stations have been elaborated for important sewage water pump types. As a result of this work, today the sewage water transport by centrifugal pumps, which is much more complicated than the conveyance of clean water is no problem anymore, if the lay out and the design of the pumps is particularly aligned to the kind of water which has to be transported. There are some remaining technical problems which can be attributed to the special impeller geometry. In case of single-blade impellers often substantial flow forces occur, which provide high mechanical loads and strong vibrations for the pump components. Sometimes this causes a pump failure or even damages at the attached pipes. But it is shown by the described examples that a reliable sewage water transport by centrifugal pumps is possible nowadays.

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ENVIRONMENT ASSESSMENT AND EVALUATION

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IMPROVEMENT OF REGIONAL SUSTAINABILITY ASSESSMENTS: AN ECOLOGICAL-ECONOMIC FRAMEWORK INTEGRATING TRADE AND MULTI-MEDIA POLLUTANTS TRANSFERS*

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A large number of sustainability accounting systems is currently developed: interdependences between sustainability dimensions and between regions are usually poorly addressed. A more realistic understanding of the consequences of a region's lifestyle is provided when including economic and environmental interrelations by linking multiples Input-Output tables and by assessing, in parallel, the transfers of long-range pollutant through environmental media. An ecological-economic framework is proposed and illustrated by a case study of Austria and Germany SO_2 exchanges, either embodied in trade or transferred through the air.

1 Introduction

The search for alternative measures of development has increased in parallel to the interest in the sustainable development paradigm. A large number of sustainability accounting systems is currently developed but they are usually grouping together conceptually very different types of indicators and poorly addressing the interdependences between sustainability dimensions and between regions. The EPSILON[a] project (Environmental Policy via Sustainability Indicators on a European-wide NUTS III level) proposes to reduce these limitations by developing consistent new solutions.

Sustainability assessments usually draw on administrative or political boundaries as limits of the studied system. Assessing regional sustainability within these limits is however only a rough assessment of a regional situation. A European region (NUTS2/3) is not an isolated unit but is part of a larger system, the Nation, itself part of the European Union, political unit on Earth. In our highly interconnected society, where connections are multiple and interdependencies with other units are growing, looking at regional sustainability is therefore not to determine if regions are autonomous or on a path to

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sustainability on their own territory only. Interactions between regions have to be included to get a more realistic understanding of the consequences of a region's lifestyle since very few regions are self-sufficient. The calculus of "footprints" [1], for example, is extremely relevant at this scale.

EPSILON proposes to assess regional sustainability based on an ecological-economic framework that extend boundaries and integrate linkages between regions in two ways. First it suggests including exchanges of goods through trade to account for the growing specialization within Europe, and the stronger differentiation between production and consumption patterns. Second, it suggests considering the bio-physical realities of the local environment and including transfers of long-range pollutant through environmental media.

This proposal is illustrated by a case study, at the national level, on Austrian and German SO_2 exchanges, either embodied in trade or transferred through the air. It shows how relevant it is to consider interactions, the interest to adopt a consumer perspective and the similarity, in term of magnitude, of economic and environmental relations. Conclusions can be applied to the regional level as well.

2 A consumer-based ecological-economic framework

The ecological-economic framework is based on Life Cycle Thinking and is consumer-focused. This means looking at the total impacts linked to consumption and attributing the emissions from the production, consumption and disposal stage to the consumer, separating direct emissions (by the consumer) from indirect ones (up and downstream) [2]. Emissions linked to the production should therefore be included wherever they occur, locally or in other countries.

Most of the studies on consumption – Australia [3], Denmark [4], except one more detailed, in the Netherlands [5] - are however only rough evaluations regarding this issue. They do not really assess impacts outside the country but assume that foreign production has the same impacts as the national ones. This clearly reduces data needs but provide high uncertainties, due to the different economic and technological structures. Trade is not realistically considered and this prevents to relate the current consumption to any producing country. These consumption studies usually focus, in addition, on global issues, like energy and/or CO_2, and do not include local pollutants e.g. SO_2, heavy metals or dioxin while they are of primary importance for some goods and for some regions.

A regional assessment framework should however deal with these local emissions and depositions since there is a high degree of variability between regional concentrations of pollutants. It should, in addition, provide information about the interrelations of a region with the rest of the world and therefore about the potential trans-boundary impacts of its inhabitants' lifestyle. The following questions should be answered:

- What are the emissions induced by local consumers?
- Where do the related impacts take place?
- Is there equilibrium between trade partners in term of environmental damages linked to exchanges?

- Does a region assume more than its share of the environmental burden?

This local sustainability perspective can be given through a joint evaluation of the impacts from current goods exchanges (trade) based on interlinked extended Input-Output tables and the parallel assessment of the transfer of long-range pollutants based on a pollution dispersion model.

3 Extended Input-Output Analysis

An extended input-output analysis joins in the same framework economic and environmental information. These frameworks are widely used for analyzing the environmental impacts of consumption patterns or for understanding how structural changes will affect the economic and environmental performance.

3.1. *Economic component*

An input-output table is a description of the flows of goods and services through an economy in financial terms. This descriptive framework is part of the System of National Account (SNA) [6] and consists of four quadrants: the first quadrant is the matrix of intermediate deliveries between the production sectors, the second represents the final uses i.e. deliveries to consumers and public institutions, investments and exports, the third one describes the other inputs of a sector i.e. added-value and imports and the last contains the primary inputs of the final demand. National input-output tables can be linked together providing that data on imports and exports is available at the sector level, both at origin and destination.

An input-output table makes therefore explicit the links between the production structure, the imports, the quantity of goods delivered to consumers and exported for each sector as well as the creation of wealth (added-value) by each of them.

3.2. *Environmental load*

These tables can be extended by using environmental accounting data, e.g. Nameas or other emissions data, resulting in an extended input-output table with a new quadrant, the emissions factors per sector (CO_2 emitted per € of total output, for example).

Data on this environmental load per sector is being standardized in Europe. Two main sources are available: some statistical offices publish yearly data for the main air pollutants e.g. CO_2, CH_4, SO_2 and the European Union provides data (Nameas), trough EUROSTAT in collaboration with EU members States.

“Namea” stands for National Accounting Matrix including Environmental Accounts [7]. It is a broadening of the scope of the conventional System of National Accounts. The core of the framework is a national accounting matrix (NAM), The environmental accounts (EA) present the environmental requirements of the economy, e.g. the material inputs (natural resources, energy) and the output (emissions to air and water, waste). They are denominated in physical units. The current preliminary version (2004) includes outputs to air: emissions of SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, NH_3 from industries, services and households. This framework is presenting data in a different way than in traditional emissions statistics (e.g. Corinair), since it includes only national economic activities: it does not cover natural emissions or anthropogenic emissions from other sources than national ones.

3.3. *Analytical framework*

The first strength of extended input-output approaches is to allow a comparison of countries on the basis of the direct emission intensities of their production sectors. This is however only a partial picture, since different production structures e.g. the reliance on more imported goods, logically results in different emissions intensities. The emissions along the upstream chain of production have therefore to be accounted for. These indirect emissions have to be emitted to allow for the current economic activity i.e. extraction and treatment of raw materials, production of goods and infrastructures used in the production process, transport and administrative activities. Input-Output tables can be transformed for this analytical purpose into a Leontief Inverse. [8]

4 Transfer of long-range trans-boundary pollutants

Pollution dispersion models describe the fate of a pollutant within the environment. They model the transport and deposition of pollutants according to the place of emission, the atmospheric and meteorology conditions as well as chemistry and land use.

Some models propose estimates of the destination of a pollutant according to its place of emission as well as estimates of the origin of a pollution deposited in a specific area. The EMEP model [9] results have been used in the case study.

5 Case study objectives

This case study concentrates on the exchanges between Germany and Austria, countries with good public data availability and using SO_2 as a test substance. It illustrates how benchmarking of sustainability between countries increase in meaning when including economic relations (in terms of pollutant embodied in traded goods) and environmental relations (pollutant transfer through the air). How to account for emissions occurring in another area? Are transfers through the environment relevant and how do they compare to the pollutant content of exchanged goods?

6 Methodology

Three different steps, related to different data and issues, are required for performing this evaluation. They are described below.

6.1. *Calculus of embodied emissions of traded goods*

The calculus of embodied emissions of traded goods is based on linked Inverse matrices of Leontief. The concept of embodiment represents the emissions emitted for the production of a good and not only the pollutants incorporated in this good. All emissions (direct and indirect) are attributed to the final demand. Direct emissions from the production of a good A, consumed by a final user, are completed by the emissions occurring during the production of the intermediary goods (B & C) required to produce this good A.

Since SNA is based on the residence principle further modifications have however to be applied for accounting for the proper location of emissions. The residence principle means that the emissions considered relate to the national economic activities rather than to the activities on the national territory. Corrections mainly relate to tourists and transport activities.

When adding the impacts occurring during the use and the elimination phase, it is then possible to know the real burden of items consumed by residents and non-residents in a country. Emissions from the use phase are the emissions emitted directly by the consumer e.g. CO_2 while driving a car.

For each traded good, it is therefore possible to define the embodied SO_2 content, at the sector level, by building a two-country model for the assessment of the bilateral exchanges.

6.2. *Assessment of Environmental transfers*

The calculus of SO_2 transfer is based on source-receptors relationships from EMEP [10]. They are linking changes in air concentrations or depositions resulting from a change in emissions in an emitter country. The assumed causality between an emission in a country and the resulting deposition in another area is therefore estimation.

6.3. *Joint assessment and indicators elaboration*

Different types of indicators could be elaborated. Some are purely based on Input-Output, like the environmental balance of trade, comparing the embodied content of imports and exports. We will here compare the magnitude of environmental transfers with embodied emissions linked to trade.

7 Data sources

Official statistics from the statistical offices of Germany [11] and Austria [12] have been used for the economic Input-Output tables and the SO_2 emission for calculating the environmental load per sector. Environmental data has been completed with a preliminary version of the Nameas [13] and official data provided by the countries to UNECE [14]. A combination of sources has been necessary to account for the direct emissions from consumers and for attributing emissions to residents outside the country and to non-residents within the country. Trade data is from the OECD STAN bilateral trade database [15].

The data for SO_2 transfer between countries is taken from the EMEP model. The main objective of the EMEP programme is to regularly provide governments and subsidiary bodies under the CLRTAP (The cooperative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe, linked to the Convention on Long-range Trans-boundary Air Pollution) with qualified scientific information to support the development and further evaluation of the international protocols on emission reductions negotiated within the convention. EMEP provides trans-boundary pollution data for SO_2, Heavy Metals and Persistent Organic Pollutants. These data include emissions, modeling and measurement data.

8 Assessing exchanges between Austria and Germany

8.1. *Attributions of SO_2 emissions in Austria*

Changing the attribution scheme of emissions from a direct causality to a consumer perspective is the key to allocate emissions between different areas. It also provides a different vision of the potential responsibilities related to sustainability. The following example shows the two different allocation methods, considering Austria as a close economy. Direct emissions of SO_2 in Austria (Figure 1) are clearly dominated by the industry. Allocating embodied emissions to the sector providing the final goods to the consumer (Figure 2) shows that the activities of the service sectors are linked to more than 30% of emissions. Consumer emissions represent direct emissions and are therefore the same in both cases.

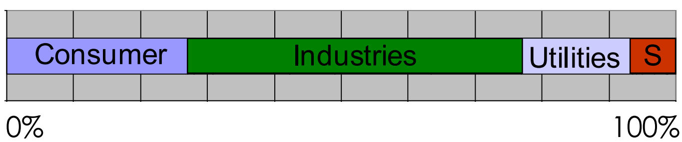

Figure 1. Distribution of direct emissions (SO2) in Austria.

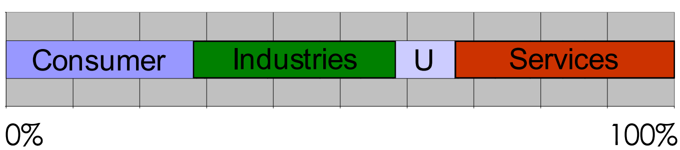

Figure 2. Distribution of embodied Austrian emissions (SO2) to the sector providing the goods & services to the consumer.

8.2. *Fate of Austrian SO_2 emissions and origin of Austrian concentrations*

Figure 3 and 4 illustrate how crucial it is to account for trans-regional pressures when assessing regional sustainability and how incorrect it is to look only at the local environmental Pressures from local socio-economic activities. The SO_2 Austrian emissions (Figure 3) are widely dispersed and only 26% stay in the country. Germany receives 6% of these emissions.

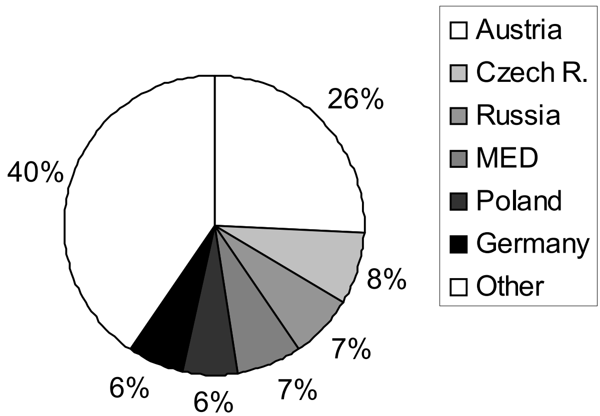

Figure 3. Seven main receptor areas from Austrian SO2 emissions (in %) (source: EMEP [16])

Depositions in Austria are also from diverse origins (Figure 4). The oxidized sulfur deposition in Austria is, for more than 80% originating outside the country. 14% is originating from Germany.

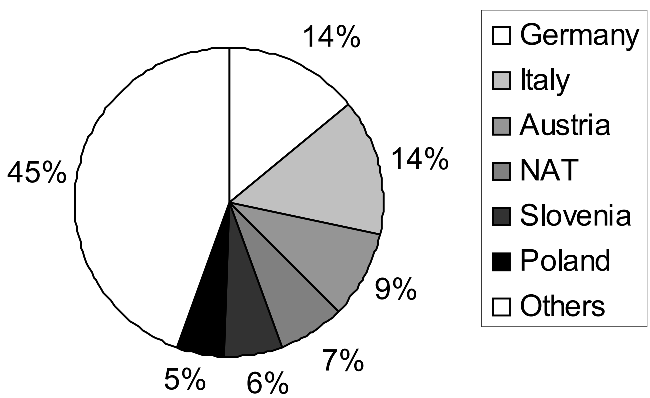

Figure 4. Oxidized Sulfur deposition in Austria (in %) (source: EMEP)

8.3. *Comparison of economic exchanges and environmental transfers*

From a monetary point of view, Austrian and German economies are tightly integrated since 43% of Austrian imports are coming from Germany and 30% of Austrian exports are going to this country. From the point of view of embodied SO_2 in trade, the numbers are quite similar. From the total emissions of SO_2 in Austria, which amount to 35Gg for the year 2000, household consumption in Austria amount for 56% and 44% (14.5 Gg) are exported. Among the exports, 30% is sent to Germany either for domestic consumption or incorporation into the production system. In the other direction, 11 Gg of SO_2 are emitted in Germany for the goods transiting trough Austria or for the Austrian consumption.

In comparison, environmental transfers amount for 16 Gg of SO_2 from Germany to Austria and 2 Gg of SO_2 in the opposite direction. This shows that embodied SO_2 in exchanged goods and SO_2 transports in air between these countries are of the same order of magnitude. Both have therefore to be both considered for a proper assessment of the sustainability and environmental pressures between the two countries. For example, the sole attribution, through embodied pollution in traded goods, of foreign pollution (emitted in country A) to a local consumption (in country B) would not be accurate if the majority of the pollution transfers, then trough the air, from A to B and is therefore already assumed by the consumer.

9 Conclusion and discussion

Preliminary results show that there is a real interest for a combined assessment since countries are interlinked both at the economic and environmental level and that linkages are of the same order of magnitude. This is even a necessity when environmental transfers are important.

This proposal can form the basis for a more complete assessment within sets of indicators: through the development of indicators comparing, e.g. the local emissions to the embodied emissions of local consumption or the environmental balance of trade.

Such illustration, performed at the national level, is however only a first step. It is perfectly valid and would be even more relevant at the regional scale since the smaller an area is, the larger are the potential interactions with the rest of the system. An extension of this proposal at the regional level would however have to deal with two other issues. First, uncertainties regarding pollution diffusion will be higher and threshold of confidence should be established. Second, the Input-Output tables have to be regionalized which is a controversial issue. Mathematical methods are apparently not sufficient and need to be completed with regional trade data. Some European countries like the Netherlands have already developed regional tables and their experience could be used for this purpose. Further extensions are also possible in the assessment of a wider range of substances.

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CORPORATE ATTITUDES TO ENVIRONMENTAL AND SUSTAINABLE TECHNOLOGY STRATEGIES

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Corporations hold a position of central importance in today's global political economy. Many observers therefore maintain that these iconic institutions must bear the main burden of responsibility for ensuring that development takes a more sustainable trajectory. This assertion is hotly disputed by those who harbour reservations about Big Businesses' intent and capacity in regards to such matters. The analysis of the changes in corporate behaviour since the 1960s reveals that despite beginning to reset the business compass to some extent, issues of sustainability are becoming more pressing and industry seems unable to keep pace with them.

1 Introduction

Corporations hold a position of central importance in today's global political economy. Many observers therefore maintain that these iconic institutions must bear the main burden of responsibility for ensuring that development takes a more sustainable trajectory [1]. [2], [3], [4]. This assertion is hotly disputed by those who harbour reservations about Big Businesses' intent and capacity in regards to matters beyond their conventional bottom line. Strategic corporate responses to calls to promote positive environmental and social outcomes as they pursue profits have ranged over time and between companies from outright denial to the development of management perspectives that go beyond 'doing things differently' towards 'doing different things'. Even more radical proponents of sustainability argue for 'being different things'.

Corporate attitudes have changed first to the environmentalism in the 1960s and later to sustainability. They have varied over time and amongst different business sectors in regards to the depth and character of corporate understandings of environmentalism and sustainability, including the use of technologies. This has resulted in changes in management strategies, but has the progress in these areas been satisfactory?

2 Corporations and Environmentalism

Evolving trends in the transformation of business attitudes to environmentalism have been noted [1], [5], [6]. The existence of such transitional stages raises interesting questions: how and why did this transformation of industry occur? How radical have the changes been – are they profound alterations to institutional outlook or do they simply amount to 'greenwashing' in an attempt to deflect attention [5]? Hoffman [5] notes that to answer the 'how' questions, a historical review is needed: "How corporate activities were perceived in the 1960s, 1970s, 1980s and 1990s is a subjective reflection of the historical context in which they were observed. In point of fact, no corporate activity is objectively defined. Whether it is a smokestack, an environmental accident, or a corporate environmental strategy, each action or issue is conceptualized based on the context at its inception" (p 6). This means that changes in corporate responses to environmentalism should not be portrayed as following a Darwinian progression from naïve to superior attitudes. The prevailing attitudes of any given moment must be regarded in their proper context – that is in relation to the beliefs and circumstances of the time. If we are to criticise corporations for peddling the eschatological myths of progress in order to promote their own agenda, it would be a strategic error to underestimate their capabilities and understandings. It is not entirely within corporations' discretion to determine what environmentalism or sustainability means or should mean to them, as the growing debate about the importance of stakeholders demonstrates.

Since the environmental movement of the 1960s began, corporations have faced the scrutiny of critics concerned about the environmental and social effects of business operations. The corporate response to this attention has ranged from initial widespread denial to increasing preparedness to engage with environmentalism and sustainability to a degree that ultimately re-orientates business ethos. The prognosis for corporate attention to environmental issues has not always been encouraging. Downs [7], for instance, predicted that a form of public mental exhaustion would eventually erode the importance of environmental issues within society. He thought that public interest in environmentalism would decline after its initial infamy; the general enthusiasm for the cause would wane as the difficulties and costs of attempting to alleviate ecological issues became clear, and another issue would take centre stage. However, this does not appear to have been the case.

Environmental issues are a potential source of cost and liabilities for businesses, particularly when mishandled, but they also provide financial opportunities for business. Various programs and policies have been implemented by management in order to 'green' corporations [6], underpinned by changing interpretations of environmentalism. Issues such as pollution, waste and water usage, pertaining to most corporations have been the subject of highest level of scrutiny and regulations.

The dynamic interaction between corporations and environmentalism continues to play out in various manifestations. Theorists have noted sequential shifts in corporate attitudes towards environmentalism that do not seem to have reached a final resolution as yet. Jamison, for instance, notes that corporations' fundamentally oppositional stance of the late 1960s to early 1970s gradually yielded to a 1990s' concern with attuning modernisation more carefully to ecology ([8], pp 123-124).

Hoffman [5] brackets these businesses' concern with environmentalism into four distinct stages:

1. Industrial environmentalism (1960 - 1970);
2. Regulatory environmentalism (1970 – 1982);
3. Environmentalism as social responsibility (1982 - 1988), and
4. Strategic environmentalism (1988 – 1993) ([5], pp 12-13).

Hoffman refers to the 1988 – 1993 period as 'strategic environmentalism'. He suggests that a more equal balance of power developed between corporations, government and civil society, which prompted industry to move proactively. The focus remained on industry's ability to deal with issues itself. The firm's organisational boundaries were increasingly interpreted as being flexible. External pressures therefore had a more direct impact than in previous times. This demonstrates that companies are social products rather than rational inevitabilities. The firm's license to operate depends to a large extent on the subjective social evaluation of its activities, rather than simply the pursuit of profit. It also highlights the fact that firms are dynamic, complex networks with multiple social influences. They are not monolithic. "In the end", says Hoffman [5], "the firm is a reflection of the society of which it is a part – not directly, but as mediated and filtered through its institutional environment" (pp 13-14).

Corporate responses to environmental issues are understandably linked to the desire to enhance competitiveness in order to increase profitability ([6], p 16). This can be achieved in various ways, including: improved product quality, increased staff commitment, improved safety record, reduced risk exposure, lower finance costs, improved public relations record, assured present and future compliance, reduced waste management costs, better utilisation of by-products, reduced downtime, improved materials and energy efficiency, enhanced yields, new management techniques and establishment of new pattern of company behaviour. There is abundant evidence attention to environmental issues leads to profitable results for business, and that managers should therefore be interested in investing in environmental strategies which either deliver positive returns or minimise risk.

Corporations with a history of creating environmental or social damage face the prospect of having to deal with lawsuits or conforming to legal requirements to clean up contaminations. This has been the case in the US in particular but it is becoming more prevalent elsewhere in the world. Firms respond to these threats and opportunities in different ways and rates. The variation between businesses and sectors can be partly understood by considering the way managers deal with uncertainty when making decisions. Managers may not be confident that they have sufficient or accurate information about the likely costs and benefits of environmental management; they may be unsure about how well new technologies are likely to perform; the transaction costs involved may be beyond the scope of the firm to cover; and/or managers may not fully appreciate the advantages to be gained by getting to grips with environmental issues [6].

Rhee and Lee [9] looked at two case studies of Korean companies to determine whether differences existed between rhetoric and reality, and whether they play different roles. They identify "gaps between the rhetoric and reality of (corporate) environmental strategy" and note that "rhetoric changes faster than reality" (p 187).

Some major changes in the last few decades gave raise to the understanding that sustainable development can only be achieved through the use of sustainable technologies. What are they and how can countries and companies position themselves against this trend?

3 Beyond Environmentalism: The Challenges of Sustainability

Hoffman [5] suggests that corporate attention to sustainability differs from the earlier meeting with pure environmentalism in that industry is now an active contributor to the framing of the sustainability debate. He contrasts this with the resistance to environmental regulation typical of American oil and chemical companies of the 1970s (p 222). However, drawing on its knowledge of environmental management, industry tends to focus primarily on the ecological aspects of sustainability rather than the social ones ([5], p 222).

The first sentence of the first chapter in the World Business Council for Sustainable Development (WBCSD) book Eco-efficiency: the Business Link to Sustainability, clearly illustrates the point: "(i)ndustry has a next century vision," says Edgar Woolard, in his capacity as CEO of DuPont, "of integrated environmental performance" (DeSimone and Popoff [10], p 1). The ambition may be '21st century' but the habit of conflating sustainability with environmental performance is very much 'last century'. Woolard also allocates responsibility for the practical 'performance' part of environmentalism to industrial corporations: "(t)he green economies and lifestyles of the twenty-first century may be conceptualised by environmental thinkers, but they can only be actualised by industrial corporations" ([10], p 1; our emphasis). The WBCSD summarises the business responsibilities for sustainability as:

- Taking account of the entire life cycle of goods and services – design and engineering, purchasing and materials management, production, marketing, distribution, use, and waste management.
- Applying the principles of eco-efficiency to create increased value for customers through the sustainable use of resources.
- In its role as consumer, procuring and requesting products and services that have less environmental impact.
- Making accurate, scientifically sound environmental information available to customers and the public so that they can make informed decisions about purchasing, use, and disposal ([10], 15-16).

The failure to appreciate socio-cultural issues as essential foci of sustainability extends not only to stakeholders surrounding business, but to the nature of business itself. Springett [11], believes that: "(t)he discourse of the 'greening' of business generally fails to address the profound change in the social role and nature of business and other institutions that is generally called for by the radical political and democratic goals attributed to sustainable development" (p 2).

4 Eco-Efficiency

Business's central platform to date has revolved around eco-efficiency [2]. Eco-efficiency is a management philosophy that fits comfortably with the dictum 'what gets measured gets managed' and the implication that sustainability, like the environment, is something to be 'managed'. Stigson, executive director of WBCSD states: "(e)co-efficiency catches at a glance the balance business strives toward: sound ecology and profitable operations. Quite simply, it is about doing more with less, and being environmentally responsible" ([10], p xiii).

Within this framework, goals are set that and progress towards them can be accurately measured. Some targets (eg 'zero emissions') are proposed in the full knowledge that they are theoretically impossible but represent a sensible general direction to head in. Eco-efficiency itself is more a process than a destination, making it unlikely that final targets will be agreed upon and reached once and for all [10], [12].

The 'eco' in eco-efficiency is designed to refer to both ecological and economic concerns, in terms of the need to "make optimal use of both" ([10], p 2). As a strategy, it is hoped that eco-efficiency will provide sustainable growth, based on a qualitative change in the nature of business growth [10]. Quantitative concerns retain primacy, supported by qualitative changes.

There are other approaches concerned with resource productivity, such as Cleaner Production (a UNEP initiative), total quality management and design for environment, including life cycle analysis (LCA). While eco-efficiency has much in common with these systems, it has distinctive features including: an emphasis on value creation; on stretching, long-term, targets for improvement; on linking environmental excellence with business excellence; and consideration of the need for both sustainable consumption patterns and production patterns ([10], p 11). The goal of promoting sustainability by improving eco-efficiency is a potentially lucrative one for corporations, and one that is not at odds with their conventional directives. This is illustrated in the way the Dow Jones Sustainability Index (DJSI) regularly outperforms the Dow Jones. Between 1995 and 2001, the DJSI posted an annualized return of 15.8% in comparison to the Dow Jones' 12.5% [13]. The Dow Jones is not intended to be an absolute measure of companies' contribution to sustainability; it aims to highlight best-of-sector performances. In fact, the people behind the DJSI admit that there are no sustaining companies as yet [14]. At this stage therefore, it primarily demonstrates that attention to sustainability issues can enhance business performance. It does not prove that it is actually possible to have 'sustaining' corporations.

Eco-efficiency strategies do not constitute a fundamental challenge to corporate identity. What has occurred, as Stigson notes, is that the concept of eco-efficiency has sparked a shift from merely increasing 'resource productivity' towards genuine innovation, from producing goods to offering services and from a focus on the individual corporation as actor to sectoral accountability ([10], p xiii). Pollution and resource use have been thought about in novel ways, for example: 'source reduction approaches such as pollution prevention and design for environment are increasingly preferred to "end-of-pipe" methods that are expensive and simply transfer pollution from one medium to another' ([10], p 1).

For example, LCA is an important component of eco-efficiency strategies. It involves looking at a product's entire life cycle, from resource to waste – 'cradle-to-grave' – in order to identify and minimise overall inefficiencies. In this way companies ensure that their best efforts to promote eco-efficiencies are not simply undermined by failures elsewhere in the chain of production and consumption [10], [14]. Systems approaches such as this are essential to sustainability. The EU governments work together with business to encourage LCA. The Integrated Product Policy was developed in an attempt to move beyond policies that focus on point sources of pollution and degradation and to encourage LCAs instead [15]. It is the result of collaboration between a range of stakeholders who wished to promote sustainability and simultaneously enhance business competitiveness.

Companies now are frequently seeking to develop shared values and stakeholder engagement with customers, suppliers, and stakeholder organisations that are brought into the sort of strategic collaboration "that many management theorists are now advocating" ([10], p 11). These aspects of eco-efficiency demonstrate the sense in which it is an innovative management philosophy. The theme of needing to produce more using fewer resources is a common one amongst business and sustainability theorists. There are several renowned examples, including Factor Four, Natural Capitalism, and The Natural Step. Müller and Koechlin [16] point out that efficiency, and as a corollary eco-efficiency should be obvious foci of management science: "Even without ecological pressure a good management will seek to improve its efficiency on purely financial grounds. However, the parameters of efficiency are subject to change, i.e. environmental resources that were previously free will be taxed and thus have a price tagged to them. This means that the managerial concept of efficiency becomes increasingly an ecological one. True efficiency will in the long run never be incompatible with ecology" (p 36).

While business endorses eco-efficiency, others prefer notions such as sufficiency, consistency or eco-effectiveness. Voices from certain non-government organisations (NGOs) dedicated to ecological issues promote the idea of sufficiency, that is, "self-limitation of material needs, withdrawal from the world-market economy and an egalitarian distribution of the remaining scarce resources" ([12], p 269). Huber suggests that even in combination these two concepts are inadequate. He argues that consistency is needed, which in practical terms might be achieved via industrial ecology, which "aims at an industrial metabolism that is consistent with nature's metabolism" and represents more than an incremental shift in strategy ([12], p 269). McDonough and Braungart [17] prefer the notion of eco-effectiveness to eco-efficiency, arguing that in nature excess is often produced but that it is not wasted as a rule. They recommend the cradle-to-cradle style of design which involves conceptualising products in a closed loop where materials are reused again and again.

5 Framework Conditions and Voluntary Initiatives

Business groups such as the WBCSD and many businesses themselves acknowledge the need for 'framework conditions' such as regulation to complement voluntary initiatives [10]. One argument put forward by companies concerned about the costs of activities such as greening the supply chain, for instance, is that they might suffer competitive disadvantage if they attempt it while others do not. They therefore argue for government regulation to level the playing field [18]. Kolk ([19], p 290) observes that "(t)he existence of legislation, originating primarily from Europe and perhaps Japan, contributes to maintain a certain level of sustainability reporting, both in quality and quantity. Moreover, there are a number of companies where reporting, either compulsory or voluntary, has been accompanied by the routine collection and/or calculation of environmental data, thus becoming part of regular processes".

While it is argued that while regulation might be needed to discipline recalcitrant companies which resist improving their environmental or social records, it can also impact positively on the conventional bottom line. Porter [20] concludes that rather than being an unreasonable burden, regulation stimulates the pursuit of efficiency which enhances competitiveness.

An alternative to legislative pressure is industry pressure from within through voluntary initiatives. It is now common practice for corporations to have Environmental Management Strategies (EMS) in place and to engage in corporate environmental reporting [21]. The number of firms which also use voluntary standards such as ISO 14001 or ISO 9001 as part of their EMS is constantly growing (see Figure 1 for registered ISO 14001 sites). The worldwide number of ISO 14001 certified sites has exceeded 100,000 in January 2006 (see Figure 1).

Many transnational corporations however consider their own EMS to be superior to ISO 14001. Some businesses are interested in selectively, incorporating aspects of ISO 14001 that they feel might enhance their own EMS, but are less convinced of the benefits of investing time and effort in order to gain certification. Some managers feel that it is likely that ISO 14001 might become a base-line market condition, as ISO 9001 did, so that corporations might have to adopt higher standards of their own to hold a competitive advantage [18]. ISO 14001 intersects with other strategies as well. The Natural Step and ISO 14001 can be usefully integrated, for example.

Supply chain management, or 'greening the supply chain', is another emerging strategy. According to the United States-Asia Environmental Partnership, supply chain management "represents perhaps the greatest opportunity for raising industrial environmental performance on a global basis" ([18], p 6). Companies may work with government or non-government organisations to establish suitable guidelines for supply chain management. Starbucks' CEO, Orin Smith, asserts that "(g)lobal coffee production can only be sustainable if it is economically viable, socially responsible and environmentally sensitive at all levels of the supply chain" ([22], p 1). Starbucks worked with Conservation International to develop guidelines to prompt suppliers to conform to rigorous sustainability-enhancing standards [22].

Supply chain management is a natural theoretical adjunct of EMS, but in practice it is not always implemented even where EMSs are in place. This may be because the relevance of supply chains has escaped the attention of the public. Companies operating in Europe are often more proactive in terms of greening the supply chain than others, particularly where there are legal requirements to take back products once they are no longer useful. This is true of the automobile and electronics sectors, for example [18].

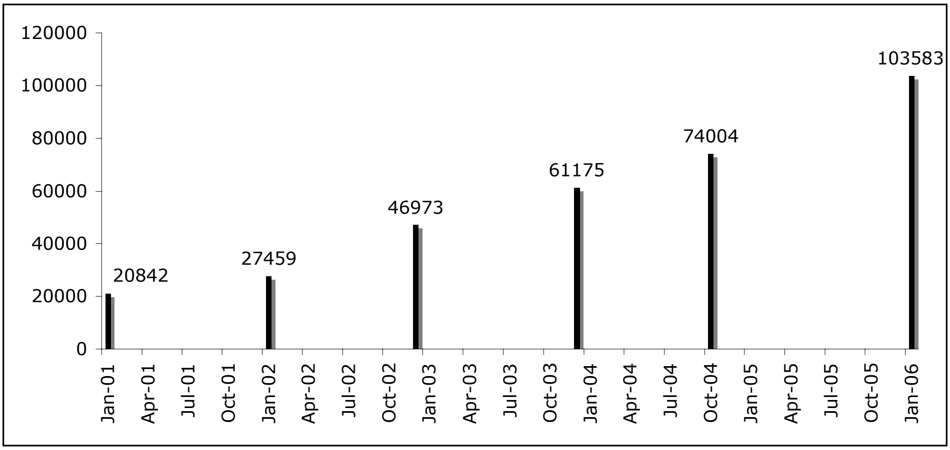

Figure 1. ISO 14001 certified sites worldwide
(Source: Compiled from http://www.ecology.or.jp/isoworld/english/analy14k.htm).

6 Reporting Sustainability

Increasing numbers of businesses are making the effort of producing reports and improving their accountability. Kolk [19] notes that corporate sustainability reporting has increased dramatically since 1998: "(f)or the largest Fortune 250 companies, it has overall risen from 35 to 45%." (p 281). He also observes that the largest, most visible multinationals are the most active in disclosing information on their environmental and social activities. The Coalition for Environmentally Responsible Economies developed the Global Reporting Initiative which "provide(s) globally applicable guidelines for economic, environmental, and social reporting' that many companies utilise [23]. The WBCSD instigated Sustainable Development Reporting in 2001 to assist companies with their reporting practices [23]. Many companies, eg Rio Tinto, Interface, ABB, IKEA and the Body Shop, now produce sustainability reports.

Another significant international initiative is the Global Compact. This is a voluntary, multistakeholder initiative launched by the United Nations in 2000, which Kofi Annan challenged business leaders around the world to 'embrace and enact' [24]. It is an "international corporate citizenship network initiated to support the participation of both the private sector and other social actors to advance responsible corporate citizenship and universal social and environmental principles to meet the challenges of globalisation" ([24], n.p.). It is built around ten principles:

- Human Rights
  - The support and respect of the protection of international human rights;
  - The refusal to participate or condone human rights abuses.
- Labour
  - The support of freedom of association and the recognition of the right to collective bargaining;
  - The abolition of compulsory labour;
  - The abolition of child labour;
  - The elimination of discrimination in employment and occupation.
- Environment
  - The implementation of a precautionary and effective program to environmental issues;
  - Initiatives that demonstrate environmental responsibility;
  - The promotion of the diffusion of environmentally friendly technologies.
- Anti-Corruption
  - The promotion and adoption of initiatives to counter all forms of corruption, including extortion and bribery [24].

There is some acceptance within the business community of the value of using triple bottom line (TBL) analyses as an accounting method of considering all three areas of sustainability. The triple bottom line focuses 'on economic prosperity, environmental quality and – the element which business had preferred to overlook – social justice' ([25], 70). For example, Soupata, CEO of UPS, supports the need for TBL accounting because he considers that: "(t)here is a responsibility that comes with being a global firm. Companies need to have a positive impact, both short and long term, on the communities they do business in" ([26], 18). The notion of 'value' is increasingly being used in relation to sustainability issues, and it is a familiar notion in business – the primary aim of companies is to create and deliver value [27].

The assertion that corporations have social responsibilities beyond that catered for by the pursuit of profit is often met with indignant rebuttal, however. Zadek comments that: "making business logic out of a deeper sense of corporate responsibility requires courageous leadership – in particular, civil leadership – insightful learning, and a grounded process for organisational innovation ([28], p 132).

7 Conclusion

This business orientation towards efficiency in relation to the use of environmental resources and in production methods as the key strategy for sustainability is referred to as 'ecological modernisation' or 'eco-modernisation' [6], [8]. Eco-modernisation "tries to understand the ways in which institutions, like business, integrate environmental and economic objectives as part of an overall process of social change" ([6], p 23). The social objectives are missing in this equation – the process of 'greening' business is often informed by the familiar territory of environmental management than the more complex and challenging sustainability objectives. Eco-modernisation is the theoretical expression of the wish to perpetuate industrial society by simultaneously encouraging economic growth and environmental responsibility. Robbins says that this aim is a product of the efforts in the 1980s and 1990s to decouple, integrate and converge environmental and economic concerns that were viewed as contradictory in the 1960s and 1970s ([6], p 25). In this way, eco-modernity tames the radical by enclosing it in acceptable language and institutionalising it. Critics fear that as a result of this process environmentalism and/or sustainability are being 'hijacked' and rendered impotent [29]. Jamison remarks that "(w)hether we see it as cooperation or cooption, as seeking greater influence or simply selling out, there can be little denying the fact that much of what was once a movement comprised primarily of voluntary activists has gone to market" ([8], p 124).

Although business action in regards to sustainability has been commendable it is insufficient, since the "industry leaders (in this field) are outnumbered by the laggards" [30]. Furthermore, gains in sustainability have been offset by economic growth and rising consumer demand. The result is that '(b)usiness efforts to reduce environmental impact are not keeping pace with the worsening state of the planet' ([30], n.p.).

In general, a trend is observed for businesses to gradually change from initial resistance to external criticism and pressure in regards to environmental and social issues to more positive engagement. Increasing numbers of corporations are now providing sustainability reports for public scrutiny. Additionally, researchers have noted a widening range of vision from a management focus on issues within a single company, to an appreciation of the importance of understanding and actively engaging in networks and collaborations with a range of stakeholders. Along the way, there is much discussion about what Big Business's role in society should be – themes such as corporate social responsibility are highly debatable.

While many initiatives are applauded, critics fear that corporations are essentially 'hijacking' sustainability and unhelpfully distorting its core themes. The eco-modernist tendencies of the business response to sustainability – such as the reliance on eco-efficiency – are controversial. Some doubt whether the culturally specific promises of modernity suitably uphold sustainability's global ambitions concerning cultural and ecological diversity. It is important to note that variations in corporate attitudes to environmentalism and sustainability over time should not be interpreted as a Darwinian progression from naivety to sophistication. They are responses to the changing social understandings and contexts in which corporations are embedded. While it is necessary to critically analyse the sincerity and suitability of corporate responses to environmentalism, it is also important to avoid treating them in a patronising manner emanating from a Darwinian perspective.

The journey continues and may eventually come to involve a profound transformation of corporate identity and function. The meeting between business and sustainability is an inevitable and desirable step. Whether it will provide the sort of outcomes activists might have wished for is yet to be determined. The existing paradigmatic version of corporate identity has stretched to accommodate eco-modernisation, but it is possible that in future, devotion to sustainability will catalyse a shift to a new model of doing business within a new system. Despite beginning to reset the business compass to some extent, issues of sustainability are becoming more pressing and industry seems unable to keep pace with them.

Acknowledgement

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ABOUT THE ENVIRONMENTAL IMPACT OF BUILDINGS: ANALYSIS OF BUILDINGS USE INCIDENCE IN THE ENERGY CONSUMPTION

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The consideration of the use, as one of the factors of greater incidence in the final energy consumption in the buildings, is the initial approach of this work that proposes a methodology to quantify, to value and to analyze this influence. Understanding, that the use is not only referred to the activities that are developed into a building, but also to the energy resources that utilizes to carry out these activities and to satisfy the comfort needs of users, the total consumption of energy will be related to the different energy uses in the building. Taking as premise that for each energy use the consumption should be related to the systems and available machines in the building, its performance and the use that be done of them, if we consider each one of these factors as a variable to know, the energy consumption would be defined according to the solution of the following equation: EC = IP * P * U, Eq. (1), where are: EC - energy consumption, IP - installed power, P - performance/efficiency of systems, U – use and * - variables operator (to define). The analysis and the resolution of this equation suppose the initial approach to verify by the study of some UPC buildings within a PhD thesis investigation, in the framework of different research projects promoted from Environmental Plan Office at UPC.

1. Problem Definition

For some energy uses (electrical appliance uses, f. exam) the variables of proposal equation corresponds to fixed values relatively easy to identify because are not associates to “external factors” that can modify them. In other energy uses as the artificial lighting or the HVAC systems these variables can have a great variation in function of these factors that influence in the definition of each one of them. In the case of the HVAC systems, for example, the first variable (IP) is related to factors as: the comfort parameters, the building type, the constructive and architectural characteristics, the climate in which be located, and the use or uses that be given. In this case the concept of “Installed power” will be changed to “the energy needs of the building” (Demand).

For the “Use” variable is necessary to distinguish between the use of buildings space’s, and the energy resources use, because other type of factors would affect. Respect to the use of the different spaces of building would be considered the singularities and habits of the users (hours of not predict use, unexpected volume of users, etc.) and

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respect to the use of energy resources with the consideration that from the design of the systems installed into the building to attend the energy demand (finally, the energy consumers) a typified use is assumed and probably is not the final real use and can have a great influence in the performance of the systems (P). Assuming those considerations the Use variable probably need to be considered as the Use management variable that include it. Taking in account as it exposed, the equation initially presented for the energy uses, in the case of HVAC uses would be modified in the following way:

$$EC = D * P * U_m, \tag{2}$$

where are: EC - energy consumption, D - energy demand, P - performance of systems, U_m - use management and *** - v**ariables operator (to define).

It is easy to deduce that the use has a great incidence, not only into the Use management variable, but in greater or smaller measure in all variables of this equation. The solution of this equation intends to identify and to quantify, if it's possible, this incidence.

Understanding that the approach would be able to adapt to the singularities of each energy use, this work is focused into the analysis of the energy consumption for the HVAC needs because as the possibles energy uses into a building has the major role in the final consumption (between 40-60% according to the building type) and supposes the greater architecture, and architect as the designer, incidence.

2 Achieving Data

The analysis of initial approach was developed studying the energy behaviour and the characteristics of some buildings with differences and similarities respect to the factors that would influence the energy consumption: The Location, The building characteristics, and the Use. Taking as a premise that a university campus can offer different typologies of buildings, 6 UPC buildings were selected with the following characteristics (Table 1).

Table 1. Selected buildings.

Campus Buildings	Autonomous Buildings
• **C-3 Building**: (Mix use :Offices, Labs, Classrooms) • **D-4 Building**: (Mix use :Offices, Labs, Classrooms) • **A-6 Building**:(Specialized use: Classrooms)	• **EUPB**. (Technical University School of Barcelona). • **ETSAB**. (Technical School of Architecture of Barcelona) • **ETSAV**.(Technical School Superior of Architecture of Sant Cugat del Vallès .25 Km from Barcelona)

The buildings were splitted into 2 groups according to its characteristics: buildings in campus and autonomous buildings (That have all the uses to function with autonomy). The work was developed according to "Energy Audit" methodology [1] by in the first step collecting data related to the characteristics of each building, its use and the energy consumption. (Figure 1).

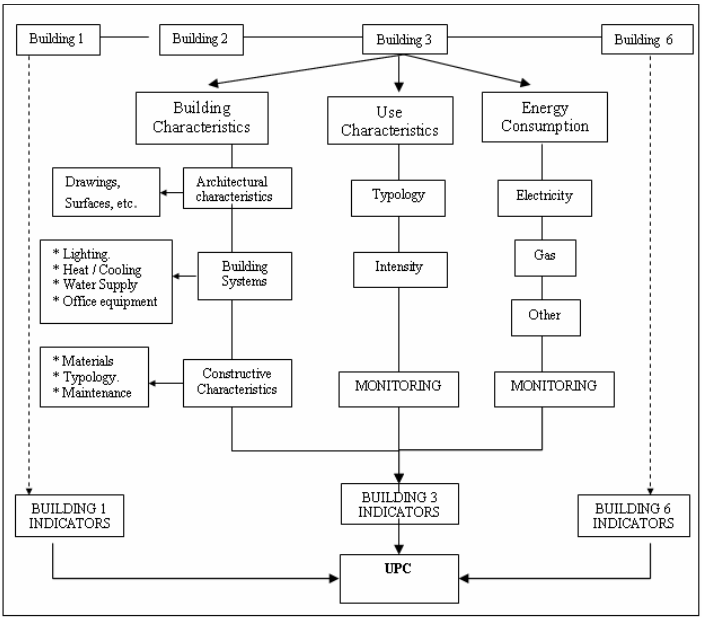


Figure 1. Energy Audits Methodology.

The monitoring of the energy consumption was carried out in periods of 1 “Reference week” by month, taking data reports of consumption each 30 minutes, 24 hours al day. In the same “Reference week” was selected a day in which was carried out a detailed monitoring of the activity in the building counting the number of users in aleatory visits, in order to obtain a reference of the building occupation along the characteristic day. On the other hand, weather data of each period were registered, to establish and to analyze the energy needs of the buildings.

The data obtained were classified in 2 ways. On one hand, the “Statics” data referred to the building characteristics (architectural, constructive, etc.), the use typology, the sources and energy uses that are utilized. These data are translated in a series of indicators that permit to quantify the different aspects analyzed. On the other hand, there is a series “dynamics” data, related to the monitoring of the use and the energy consumption that are translated in graphics and reference data bases.The static data are associates to buildings characteristics, that allow to carry out economic investments to modify them, and the dynamic data are associates to aspects that can improve only with an adequate management.

3 Variable Analysis

3.1. *HVAC Demand*

The first variable to analyze is the energy needs for heating and cooling (HVAC demand). Actually, exists different types of methodologies and tools to evaluate the energy HVAC demand of buildings, according to the type of analysis that carry out (uni-zone or multi-zone) or with the heat transfer state that consider (stationary or transient).

The following tools have been selected to evaluate the HVAC energy demand of the buildings (Table 2).

Table 2. Evaluation tools.

TOOL	Zoning type		Heat transfer state	
	Uni-zone	Multi-zone	Stationary	Transient
Simply degree days analysis [1]	X		X	
ARCHISUN tool [2]	X		X	
BALANÇ ENERGÈTIC tool [3]	X		X	
LIDER Software [4]		X		X

The results for each group of analyzed buildings are represented in Figures 2 and 3.

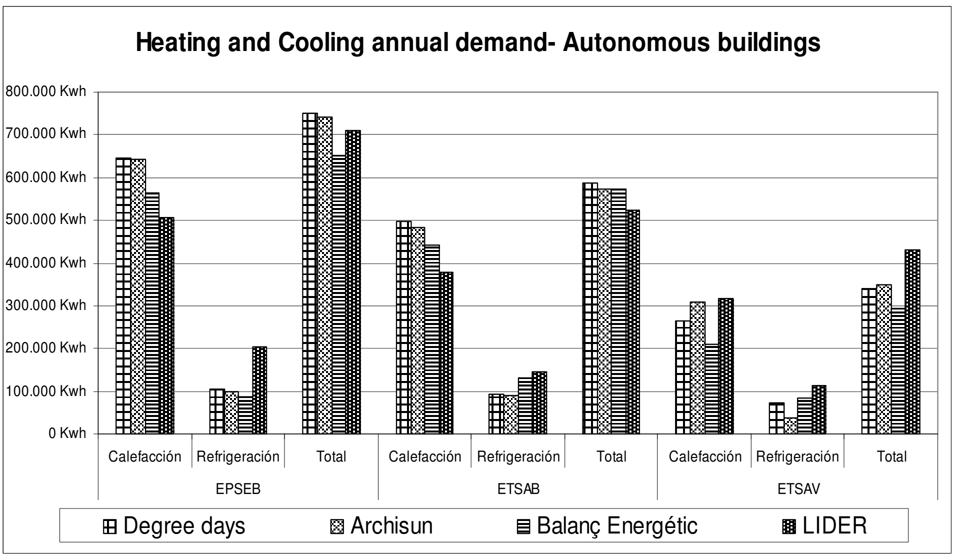


Figure 2. Autonomous building HVAC demand.

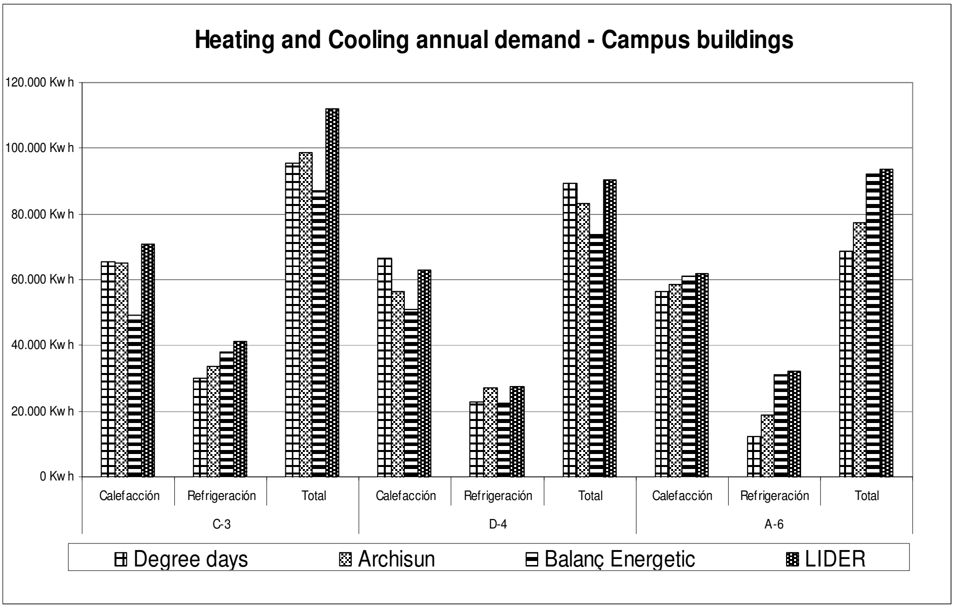


Figure 3. Campus Buildings HVAC Demand.

The analysis of the results permits to identify that the transient multi-zone methods are more detailed and exact in their analysis and permit a better simulation of the buildings singularities. This characteristic is very significant especially in case of complex geometry buildings because with simplified geometry buildings (Buildings in campus in our case) the results with respect to the uni-zone and stationary methods do not represent large differences.

3.2. *Systems Performance*

Taking as a premise, that the energy to generate the indoor building climate has different phases until its final utilization, for evaluate the overall systems performance will be necessary to evaluate the performance of each phases.

Considering the characteristics of the systems of HVAC employed in each building it's necessary to solve this equation:

$$ή = ήg \mathbf{x}\ ήd \mathbf{x}\ ήc, \quad (3)$$

where are: ή - overall performance, ήg - performance in generation of energy, ήd - distribution of system performance and ήc - control/regulation performance.

The evaluation of each performance supposes to know the quality of the installations, the characteristics of systems and the management and maintenance level that has. With the buildings raised information was possible to carry out this evaluation, qualifying between 0-100% the conditions of each aspect.

But also it is possible to utilize software to evaluate the performance of the systems according to its energy performance, by the simulation of the systems management and uses that qualify the global performance comparing with a reference building that has same characteristics and demand. In the Spanish context, nowadays is working in the development of the CALENER software [4] selected to be used in this work.

The results of the performance evaluation through the qualification of the individual performances and the global qualification with CALENER are presented in Table 3.

Table 3. System performance (*A 0.74 performance value suppose a P equation coefficient of 1.26 for example).

	BUILDING	Performance by phases ή: ήg X ήd X ήr		Performance by software tool CALENER	
		Heating	Cooling	Heating	Cooling
Autonomous Buildings	EPSEB *	74%	190%	79%	200%
	ETSAB	68%	200%	62%	190%
	ETSAV	65%	200%	72%	210%
Campus Buildings	C-3	76%	220%	78%	180%
	D-4	75%	220%	79%	220%
	A-6	80%	-	83%	-

According to the results, it is observed that some buildings have centralized installations with low global performance as a result of a wrong system design (zoning) and a minimum level of control and maintenance (autonomous buildings).

3.3. *Use Analysis*

In the case of the variable Use is necessary to distinguish between the use related to the energy resources used in the building, better defined as the management of resources, and the use related with the utilization of the building spaces.

In the case of the management of energetic resources, the interest is to know if the energy consumed in the building really attends the users comfort needs, or if is supplying energy (cold or heat) in the moments or in the quantities that are not needed, that would be translated in an inefficiency of the system. To know this inefficiency value will be necessary identify which is the incidence of the energy supply to the confort level of the building for a specific time period , or in the same way; which is the behavior of the indoor confort when is delivered the energy that the building consumes.

To carry out this analysis will be necessary to do the energy balance of the building for a specific period (a day for example in 1 hour fractions), that includes the real values of: buildings use according to the monitoring of use (number of persons by hour) the heat or cold energy really supply (according to the energy monitoring) to verify the variation of the indoor temperature in the same period.

According to the indoor temperature behaviour between defined comfort parameters will be able to establish if the delivered energy is adequate or if the building is unbalanced in this period. (Figure 4).

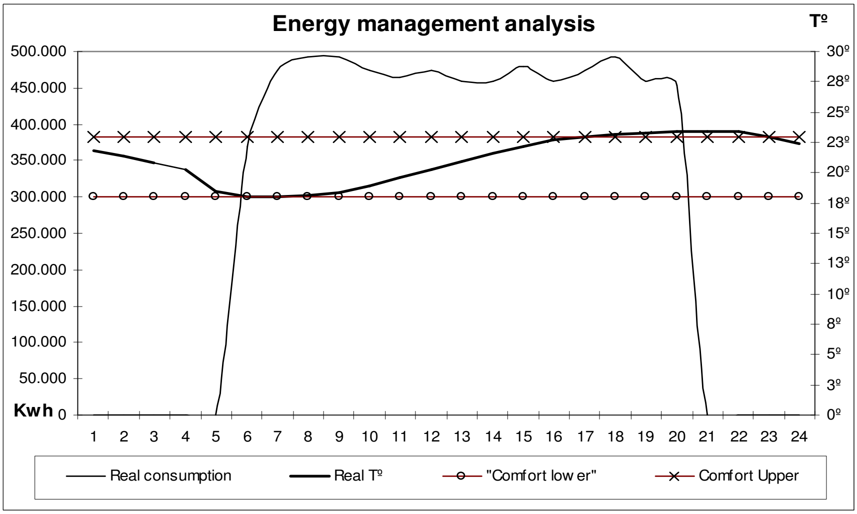


Figure 4. Incidence of delivered energy into indoor comfort behavior.

When the building be not maintained inside of defined comfort parameters should be verified if is possible to maintain it inside with less energy of the one that is consumed, and the difference between the energy that theoretically should consume (Ct) respect to which really consumes (Cr) would permit to establish the Use management inefficiency degree (Figure 5).

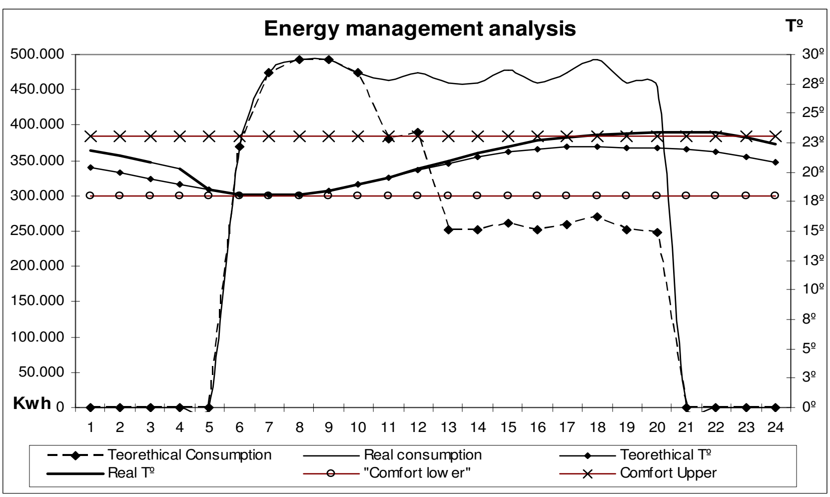


Figure 5. Possibilities to balance the indoor comfort behavior.

In mathematical terms, this would be translated like the difference between the surface of 2 represented graphics, or what is the same thing, the relation between the 2 integral functions ($\int C_t / \int C_r$) for a day period that should permit us to obtain an a dimensional value (between 0-1) which would indicate the Use management inefficiency degree (U_m):

$$U_m = \frac{\int_0^{24} C_t}{\int_0^{24} C_r} . \tag{4}$$

Obtaining a $U_m = 0{,}80$ value would suppose that the 20% of the used energy for heating or cooling are unnecessary and suppose a deficient management. The quantity of energy that this signifies in Kwh, Mj, Btu, etc. will come determined by the energy consumption of analyzed period.

To carry out this analysis would should be able to utilize any energy demand evaluation tool that allow to visualize the variations of comfort parameters (hour to hour as less) during a day type in order to extrapolate the behavior in the same way that was carried out with the values of demand for the annual, monthly, and weekly building period.

For the studied buildings, the summer period analysis reflects (save in the case of the C-3 campus building that possesses centralized cooling system) that the buildings have individual cooling systems to satisfy the needs of a minimum part of the spaces of each building (according to UPC cooling policies) with negative results of Um that will not be considered in the global analysis of Use management, because would suppose that have to consume more resources than it can consume for the machines that have.

The obtained results for each building are presented in Table 4.

Table 4. Management analysis results.

Building	**Um values winter period**				
	January	February	November	December	Average
EPSEB	0.72	0.69	0.72	0.89	**0.75**
ETSAB	0.71	0.90	0.76	0.69	**0.77**
ETSAV	0.44	0.43	0.45	0.42	**0.44**
C-3	0.79	0.72	0.75	0.88	**0.78**
D-4	0.91	0.80	0.65	0.72	**0.77**
A-6	0.94	0.94	0.93	0.80	**0.90**

4 Analysis of Propossed Equation

For each building, separated values were obtained of each equation variables; the following step will be to define the interaction between the factors.

Initially, the resolution of the equation would permit to know the energy consumption for a determined energy use (HVAC in this case) expressed in Kwh, Mj, Btu, etc. The first analyzed factor is the heating and cooling needs (demand) in terms of annual energy, if we consider that the values of demand had a greater or smaller variation for each analyzed building according to the tool of evaluation that be utilized and take into account that any evaluation tools can offers to us all the exact information of the demand, for this analysis will be estimated the average value of the demand obtained for each building with the different tools utilized, despising the upper and lower values in order to obtaining an adequate reference.

The obtained results for each building are presented in Table 5.

Table 5. Heating and cooling energy demand.

Building	Heating	Cooling	HVAC Total demand
EPSEB	535.271 kWh	145.449 kWh	680.719 kWh
ETSAB	410.745 kWh	138.493 kWh	549.238 kWh
ETSAV	263.637 kWh	99.242 kWh	362.879 kWh
Módulo C-3	61.575 kWh	37.600 kWh	99.175 kWh
Módulo D-4	56.727 kWh	25.714 kWh	82.441 kWh
Módulo A-6	61.456 kWh	31.556 kWh	93.012 kWh

The performance and the management values are considered considered as denominators with respect to the obtained demand. Therefore, for the solution of this equation, only would be necessary divide the demand value of each building by the values of performance and management to obtain the value of theoretical consumption, that if we compare with known values of real consumption from buildings monitoring, we would be able to establish a first analysis of the energy behaviour (Table 6).

Table 6. Theoretical energy consumption.

$$EC = \frac{D}{P \times U_m}$$

Building	Energy Use	D Kwh/year	P	U_m	EC Kwh/year	Real consumption Kwh/year	Difference
EPSEB	Heating	535.271 KWh	0.72	0.75	992.704 KWh	751.265 KWh	-32.14%
	Cooling	145.449 KWh	2.00	1.00	72.724 KWh	37.864 KWh	-92.07%
	Total	680.719 KWh			1.065.428 KWh	789.130 KWh	-35.01%
ETSAB	Heating	410.745 KWh	0.65	0.77	822.658 KWh	626.412 KWh	-31.33%
	Cooling	138.493 KWh	2.00	1.00	69.246 KWh	27.335 KWh	-153.32%
	Total	549.238 KWh			891.905 KWh	653.747 KWh	-36.43%
ETSAV	Heating	263.637 KWh	0.60	0.44	997.130 KWh	1.024.448 KWh	2.67%
	Cooling	99.242 KWh	2.00	1.00	49.621 KWh	8.658 KWh	-473.09%
	Total	362.879 KWh			1.046.751 KWh	1.033.106 KWh	-1.32%
C-3	Heating	61.575 KWh	0.75	0.78	105.026 KWh	96.891 KWh	-8.40%
	Cooling	37.600 KWh	1.30	0.94	30.802 KWh	23.850 KWh	-29.15%
	Total	99.175 KWh			135.828 KWh	120.741 KWh	-12.50%
D-4	Heating	56.727 KWh	0.69	0.77	106.867 KWh	123.321 KWh	13.34%
	Cooling	25.714 KWh	2.00	1.00	12.857 KWh	8.189 KWh	-57.01%
	Total	82.441 KWh			119.724 KWh	131.510 KWh	8.96%
A-6	Heating	61.456 KWh	0.72	0.90	94.460 KWh	108.465 KWh	12.91%
	Cooling	31.556 KWh	1.00	1.00	31.556 KWh	0 KWh	315.00%
	Total	93.012 KWh	0.72		126.015 KWh	108.465 KWh	-16.18%

The theoretical energy consumption obtained reflects the consumption that each building should have according to its characteristics of building, the quality of its systems and with the management observed. The difference of the obtained values with the reality of the energy consumption would indicate that the quantity of energy that supposes the real consumption respect to the theoretical needs.

But in the same way, that is possible to obtain a theoretical consumption to compare with the real consumption, if by the energy audit we would know the real energy consumption, the performance of the installations and the management, the proposed equation would be able to know the value of the real attended demand into the building (Dr), or what is the same thing, the quantity of energy that really is delivered into the building.

The initial equation presented would be transformed in the following way:

$$D_r = EC \times P \times U_m. \tag{5}$$

The comparison of the demand obtained resolving this equation with the values of theoretical demand obtained with the tools of evaluation (Table 7) would permit to establish the percentage of energy needs that are been attended with the delivered energy and in consequence, the efficiency in the consumption of resources of the buildings analyzed.

Table 7. Energy demand /delivered energy.

Building	Energy Use	Theoretical Demand (Kwh/year)	Real delivered Energy Dr (Kwh/year)	Difference %
EPSEB	Heating	535.271 KWh	405.086 KWh	75.68%
	Cooling	145.449 KWh	75.728 KWh	52.07%
	Total	680.719 KWh	480.814 KWh	70.63%
ETSAB	Heating	410.745 KWh	312.761 KWh	76.14%
	Cooling	138.493 KWh	54.670 KWh	39.48%
	Total	549.238 KWh	367.431 KWh	66.90%
ETSAV	Heating	263.637 KWh	270.860 KWh	102.74%
	Cooling	99.242 KWh	17.317 KWh	17.45%
	Total	362.879 KWh	288.177 KWh	79.41%
C-3	Heating	61.575 KWh	56.805 KWh	92.25%
	Cooling	37.600 KWh	29.114 KWh	77.43%
	Total	99.175 KWh	85.919 KWh	86.63%
D-4	Heating	56.727 KWh	65.461 KWh	115.40%
	Cooling	25.714 KWh	16.377 KWh	63.69%
	Total	82.441 KWh	81.838 KWh	99.27%
A-6	Heating	61.456 KWh	70.568 KWh	114.83%
	Cooling	31.556 KWh	0 KWh	0.00%
	Total	93.012 KWh	70.568 KWh	75.87%

The proposed equation solution and the knowledge of the quantity of energy really delivered into the buildings, allow to carry out an appraisal of the weight for each variable in the consumption, (Figure 6), that offers an overall vision of how is consumed the energy in each case.

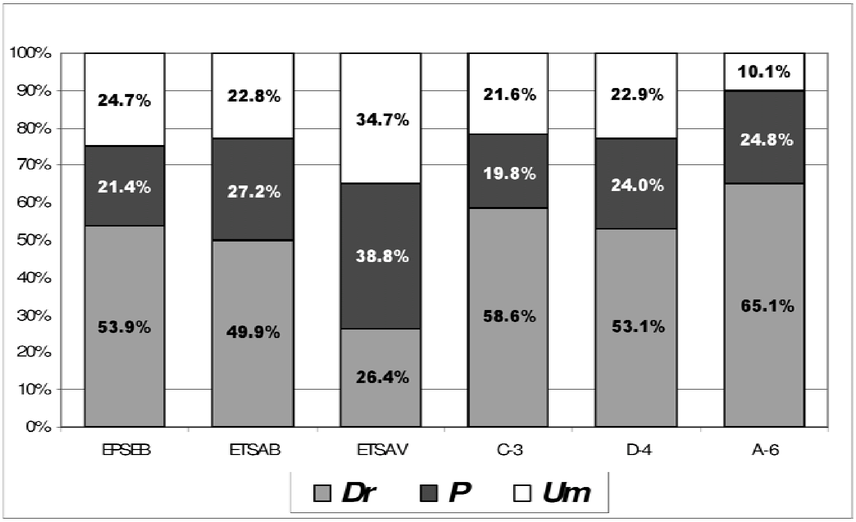
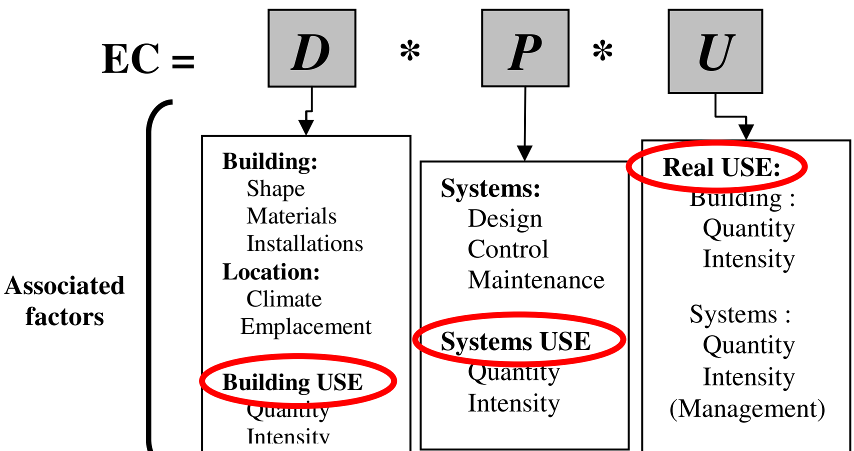


Figure 6. Weight of each variable into the energy consumption.

5 Conclusions

- The development of the work and the solution of the proposed equation permit to establish that; of the factors that influences the different variables, the Use has a greater incident in the total consumption of energy, because is the common factor to all the variables and fundamentally because conditions the variability from the values that can be obtained, measured and to simulated and the reality of the consumption:



$$EC = f\left[D(B,L,U)\,P(S,U)\,U_m(U)\right]$$

$$EC = \underset{principal}{f}\,[U]$$

- The principal conclusion of this work is that the energy consumption of a building is function mainly of the use as determinant factor (6).
- The estimation of the Use management variable of a building allow to identify the really delivered energy in a building for a specific energy use, to evaluate the efficiency in the use of the energy resources to promote energy efficiency actions and reduction of the associated impact
- The proposed methodology does not condition the tools to utilize or the depth level of the analysis. The proposed equation that shows the initial approach has been studied and analyzed utilizing some of the available tools to carry out this type of analysis. The selection of a determined tool will condition the level and the certainty of the analysis, and according to the availability and the quality of the information obtained the analysis will be more or less certain.
- The need to define an energy strategy for each building is evidenced. This strategy should define from the consideration of all phases of the cycle of life, the better form in which the energy needs of a building with the maximum performance will be attended and the best possible management that guarantee the minimum consume of energy resources.

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IMPLEMENTATION OF KYOTO PROTOCOL AND EMISSIONS TRADING

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Environmental problems that are a consequence of intensive development, competitive market, increased living standards, and energy costs have been brought into the focus of energy policy both in the European Union and in Croatia. This is especially pronounced in the Kyoto Protocol and in the energy sector liberalization processes. In this paper we discuss the possible domestic policies for the implementation of the Kyoto Protocol and their compliance with the energy market liberalisation as well as with global trading rules. Croatia as Annex I party has still not ratified the Kyoto Protocol because of the specific Croatian circumstances with respect to determination of the baseline emissions of greenhouse gases. This paper also explores the impacts of emerging environmental markets such as EU emissions trading scheme on energy sector in Croatia in line with Kyoto Protocol requirements. Directive 2003/87/EC establishing a scheme for greenhouse gases emissions allowances trading within the European Union has launched the biggest emissions trading scheme in the world. The goal is to give efficient economical measure for reducing greenhouse gases emissions in achieving Kyoto targets. Deficit with regard to allowances will be punished, and surplus can be sold or kept for further usage. Buying or selling emission allowances will have great impact on competitiveness of production facilities. With introduction of the Linking Directive 2004/101/EC with regards to Kyoto Protocol project mechanisms (Joint Implementation, Clean Development Mechanism) for emission trading EU ETS, energy utilities have a possibility to increase their emission allowances and plant production. In the paper we are considering requirements for the implementation of Kyoto Protocol, advantages and disadvantages, development of emissions trading in Europe, the influence of the same to Croatia, analysing impact of emissions trading on energy sector and business behaviour.

1 Introduction

The Kyoto Protocol [1] to the 1992 United Nations Framework Convention on Climate Change (UNFCCC), agreed in 1997, an international agreement with the aim to reduce greenhouse gases emissions world wide, entered into force on 16 February 2005. The targets cover emissions of the six main greenhouse gases (GHG): Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur hexafluoride (SF_6). CO_2 emissions cover around 80% of all GHG emissions. The maximum amount of emissions (measured as the equivalent in carbon dioxide) that a Party can emit over the commitment period (2008-2012) in order to comply with its emissions reduction target is known as a 'Party's assigned amount'. Due to the fact that the implementation of Kyoto Protocol is very demanding for national economy, there were and still are many negotiations how Kyoto Protocol is going to be applied. The main consequence of Kyoto protocol negotiations on Conferences of Parties connected with implementation, was adopting Kyoto flexible mechanisms (joint implementation, clean development mechanism, emission trading) on the seventh Conference of Parties (COP7) in Marrakesh in 2001.

Currently, four signatory states have not ratified Kyoto Protocol: USA (25% of all world CO_2 emissions) [3], Australia, Kazakhstan and Croatia. European Union has taken the leading position in ratifying Kyoto Protocol process and in the environmental protection. In 2002 the European Union has ratified Kyoto Protocol and has committed to achieve an 8% reduction in emissions of greenhouse gases compared to 1990 levels in the period 2008-2012 [17]. One of the answers to how to achieve that commitment was creation of Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community [4]. Because of the wish for linking Joint Implementation (JI) and Clean Development Mechanism (CDM) with European emission trading scheme (EU ETS) with a goal of increasing emissions quotas, the Directive 2004/101/EC [5] establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms, was adopted (27 October 2004). European emission trading scheme has started on 1 January 2005 – all plants covered by this scheme have received quotas according to the National Allocation Plans and they must monitor and report on progress made by this scheme every year.

Croatia is the Annex I Party to Kyoto Protocol. However due to specific reasons Croatia has still not ratified the Protocol. Namely, the baseline emissions year is 1990 (or earlier years), and in 1990 Croatia has had very low level of emissions due, in particular, to the fact that the emissions calculation did not include the emissions from the electricity plants located in the territory of other ex-Yugoslavia republics from which Croatia was supplied. Therefore it would be hard, if not impossible, for Croatia to reduce the 1990 emissions level by 5%.

Because of this situation Croatia has in Marrakech in 2001 proposed to the Conference of the parties to the UNFCCC (COP7) that baseline emissions for Croatia be stated at a higher level. However, this proposal has not yet been decided, and the Conference of the Parties in Buenos Aires in 2004 has decided that the decision will be prolonged to the next session in June 2005.

With the goal of joining the European Union, Croatia will soon have to ratify the Protocol and deal with its obligations.

In this paper we are considering the development of Kyoto Protocol and emissions trading scheme in the European Union and the influence of the same on Croatia, as well as the possibilities of the Protocol implementation by Croatia and the effect of it to the Croatian economy, in particular to the electricity sector.

2 Policies and Measures for the Implementation of the Kyoto Protocol

To achieve their targets, Annex I Parties must put in place domestic policies and measures. Parties may offset their emissions by increasing the amount of greenhouse gases removed from the atmosphere by so-called carbon "sinks" in the land use, land-use change and forestry (LULUCF) sector (forestation, reforestation, deforestation, forest and cropland management, grazing land management and revegetation). Greenhouse gases removed from the atmosphere through eligible sink activities generate credits are known as removal units (RMUs). European Union has already identified possible 42 measures to reduce EU GHG emissions by 664-765 Mt CO_2eq at cost below € 20/t [7].

The Marrakech Accords (2001) define guidelines, modalities and rules for the implementation of the market-based Kyoto protocol mechanisms to minimise the cost of making the required GHG emissions reductions: International Emissions Trading (IET), Joint Implementation (JI) and Clean Development Mechanism (CDM). Parties must establish and maintain a national registry to track and record transactions under these mechanisms to provide evidence that their use of the mechanisms is "supplemental to domestic action", which must constitute "a significant element" of their efforts in meeting their commitments. The Protocol rulebook sets out detailed procedures for considering cases of potential non-compliance, along with an expedited procedure for reviewing cases concerning eligibility to participate in the mechanisms.

Under the joint implementation (JI), an Annex I Party may implement a project that reduces emissions (e.g. an energy efficiency scheme) or increases removals by sinks (e.g. a reforestation project) in the territory of another Annex I Party, and count the resulting emission reduction units (ERUs) against its own target. In practice, joint implementation projects are most likely to take place where there tends to be more scope for cutting emissions at low cost. Croatia has signed a Letter of intent with the Netherlands on financing energy project of renewables implementation on the island Hvar.

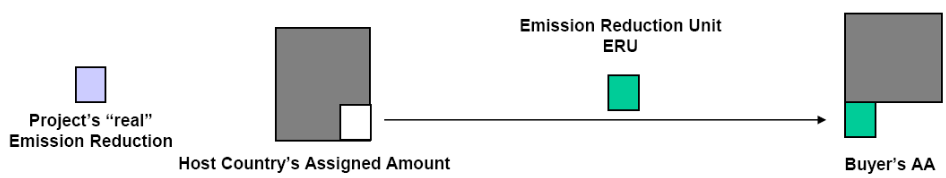

Figure 1. Joint implementation.

Under the clean development mechanism (CDM), Annex I Parties may implement projects in non-Annex I Parties that reduce emissions and use the resulting certified emissions reductions (CERs) to help meet their own targets. The CDM also aims to help non-Annex I Parties achieve sustainable development and contribute to the ultimate objective of the Convention. There are 35 different methodologies of CDM implementation, but the COP adopted only the rules of procedure of the CDM Executive Board and the simplified modalities and procedures for small-scale CDM project activities. The first CDM project has been registered in November 2004 - the project will reduce emissions of methane from a landfill in the state of Rio de Janeiro, Brazil. A successful CDM energy project can, for example, earn certified emission reductions (CERs) during a minimum of seven and a maximum of 21 years. Total Assigned Amount for Annex I countries is increased (see next figure). Croatia can, for instance, invest in cogeneration project i.e. invest in gas power plant instead of planned coal power plant in Bosnia and Herzegovina – total emission reduction can be included in total assigned amount for Croatia.

Figure 2. Clean Development Mechanism.

The idea of emissions trading system was a new approach to the problem of climate change. The Kyoto international emissions trading system was introduced based on the US's 'very positive experience with permit trading in the acid rain program, which reduced costs by 50% form what was expected, yet fully serving our environmental goals'.[20] Under the international emissions trading (IET), an Annex I Party may transfer some of the emissions under its assigned amount, known as assigned amount units (AAUs), to another Annex I Party that finds it relatively more difficult to meet its emissions target. Total Assigned Amount for Annex I countries is constant (see next figure). The Protocol rulebook requires Annex I Parties to hold a minimum level of AAUs, CERs, ERUs and/or RMUs in a commitment period reserve that cannot be traded. Tradable commodities in the emerging emissions trading markets are either GHG emission allowances (cap-and-trade system) or verified GHG emission reductions or credits (baseline-and-credit system) - these systems may be combined. Allowances and reductions are traded in various international, national and intra-company emissions trading schemes. Trading may be either voluntary or based on a mandatory regime.

An adaptation fund was established by the Marrakech Accords to manage the funds raised by the adaptation levy on the CDM, as well as contributions from other sources. The fund is administered by the GEF, as the operating entity of the Convention and Kyoto Protocol's financial mechanism.

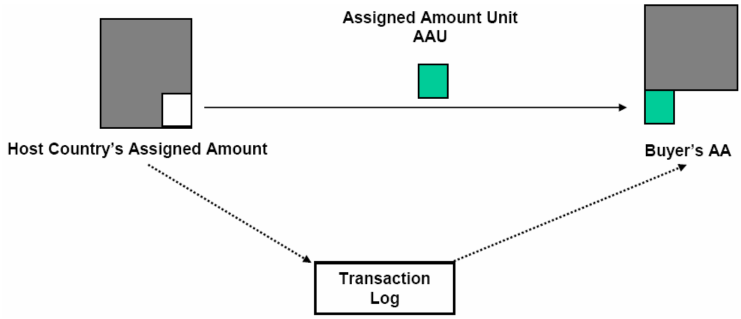

Figure 3. International emission trading.

3 Implementation of Kyoto Protocol in EU Emissions Trading and Impact on Energy Sector

EU climate change policy before Kyoto involved a strong reliance on regulation, e belief in the need to prevent hypothetical future risks caused by CO_2 emissions, a commitment to international leadership in the policy area and an internal and less-publicized realization that regulations alone were insufficient to fight climate change. [19]

"…the key to getting the incentives right through free market environmentalism is to establish property rights that are well defined, enforced, and transferable.''[22]

In January 2005 the European Union Emission Trading Scheme (EU ETS) commenced operation as the largest multi-country, multi-sector Greenhouse Gas (CO_2) emission trading scheme world-wide. The scheme is based on Directive 2003/87/EC, which entered into force on 25 October 2003. The aim is to help EU Member States achieve least cost compliance with their commitments under the Kyoto Protocol by letting participating companies to buy or sell emission allowances.

The description of such tradable emissions allowances and their purpose can be generally summarized in the following:

" Tradable permits … represent a right granted by a government to the permit holder to emit a specified quantity of gases. By issuing only a limited number of permits governments can control the total quantity of gas emitted… Because permits are usually limited to a quantity that is less than the amount of gas that would normally be emitted, the right to emit becomes a valuable commodity. If trading of permits is allowed, than a market price will be established. Those wishing to emit the specified gases beyond permitted levels must either reduce their emissions or purchase permits to emit. Polluters able to reduce their emissions relatively cheap will do so, rather than purchase permits. Those polluters who face higher abatement costs will tend to buy permits to satisfy government requirements. In this way, reductions in emissions are made by those polluters who can do so at least cost, being compensated by polluters who face higher costs of abatement.''[21]

By EU ETS emissions allowances will be allocated to approximately 12.700 installations or about 6.000 companies in the 25 EU Member States, such as refineries, power stations (units above 20 MW), paper, pulp, metal and mineral plants. Total volumes of 2.1 billion tons CO_2 per year is allocated, accounting for around 45% of the EU's total CO_2 emissions [17].

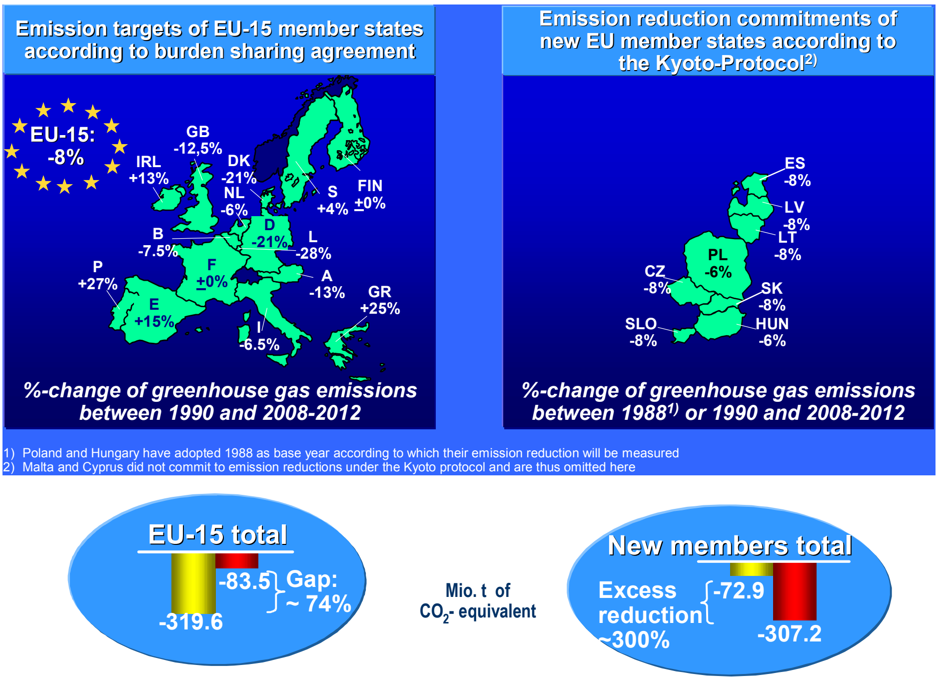

Figure 4. Kyoto protocol commitments in "old" and "new" EU Member States.

The scheme is based on six fundamental principles: It is a 'cap-and-trade' system - allocation of maximum amount of emissions rights (cap) to participants through National Allocation Plans (NAPs). Implementation will take place in phases, with periodic reviews and opportunities for expansion to other gases and sectors - two trading periods (2005-2007 and 2008-2012). Allocation plans for emission allowances are decided periodically. It includes a strong compliance framework. The market is EU-wide but taps emission reduction opportunities in the rest of the world through the use of CDM and JI, and provides for links with compatible schemes in third countries.

Recent EU Commission studies conclude that Kyoto targets can be achieved at an annual cost of €2.9 to €3.7 billion, which is less than 0.1 % of GDP in the EU. One of these studies concluded that without the Emissions Trading Scheme costs could reach € 6.8 billion [7]. Costs have to be seen in relation to the opportunities arising for suppliers of clean, low-carbon technologies in Europe and beyond and the medium-term advantage for European industry in the transition to a low-carbon global economy.

The recently adopted “Linking Directive” [5] will further lower the costs and protect the competitiveness of EU businesses. It will create a link between the Flexible Mechanisms of the Kyoto Protocol - Joint Implementation (JI) and the Clean Development Mechanism (CDM) - and the EU emissions trading scheme. In principle, companies which carry out emission reduction projects outside the EU through JI or CDM will be able to convert the credits they earn from those projects into allowances that can be used for compliance under the EU Emissions Trading Scheme – received credits will be equivalent (1 EUA = 1 CER = 1 ERU) and allow them to be traded under the scheme. This are additional incentives for businesses to invest in emission-reduction projects elsewhere, for example in Russia and developing countries. Credits from nuclear facilities and land-use, land-use change and forestry activities will not be accepted. A review will be triggered once the number of credits converted for use in the EU emissions trading scheme reaches 6 per cent of the total quantity of allowances allocated by the Member States for the 2008-2012 period. At the end of 2003, the European Investment Bank created a Dedicated Financing Facility of € 500 million to provide finance for prospective emission reduction projects. Likewise, Germany’s KfW set up a Carbon Fund in June 2004, and other leading European banks are considering similar initiatives.

National Allocation Plans (NAP) determine the total quantity of CO_2 emissions that Member States will grant to their companies, which can then be sold or bought by the companies themselves. This means each Member State must ex-ante decide how many allowances to allocate in total for the first trading period 2005 to 2007 and how many each plant covered by the Emissions Trading Scheme will receive. Quantities are not allocated to nuclear and renewables. Most allowances are allocated to installations free of charge – at least 95% during the initial phase and at least 90% in the second phase from 2008 to 2012. Though only plants covered by the scheme are given allowances, anyone else – individuals, institutions, nongovernmental organisations or whoever – will be free to buy and sell in the market in the same way as companies. Allocations to installations must take account of their potential for reducing emissions from each of their activities, and must not be higher than the installations are likely to need. Those that have not produced enough allowances to cover their emissions will have to pay a dissuasive fine for each excess tonne emitted. In the initial phase the penalty will be € 40 per tonne, but from 2008 it will rise to € 100. Operators will also have to obtain allowances to make up the shortfall in the following year, and they will be “named and shamed” by having their names published. Each installation in the ETS must have a permit from its competent authority - the permit sets out the emissions monitoring and reporting requirements for an installation, whereas allowances are the scheme’s tradable unit. Installations must report their CO_2 emissions after each calendar year.

One allowance (1 EUA) represents the right to emit 1 tonne of CO_2. Companies that keep their emissions below the level of their allowances will be able to sell their excess allowances at a price determined by supply and demand at that time. Those facing difficulty in remaining within their emissions limit will have a choice between taking measures to reduce their emissions, such as investing in more efficient new technologies or using a less carbon-intensive energy source, buying the extra allowances they need at the market rate, or a combination of the two, whichever is cheapest. This ensures that emissions are reduced in the most cost-effective way.

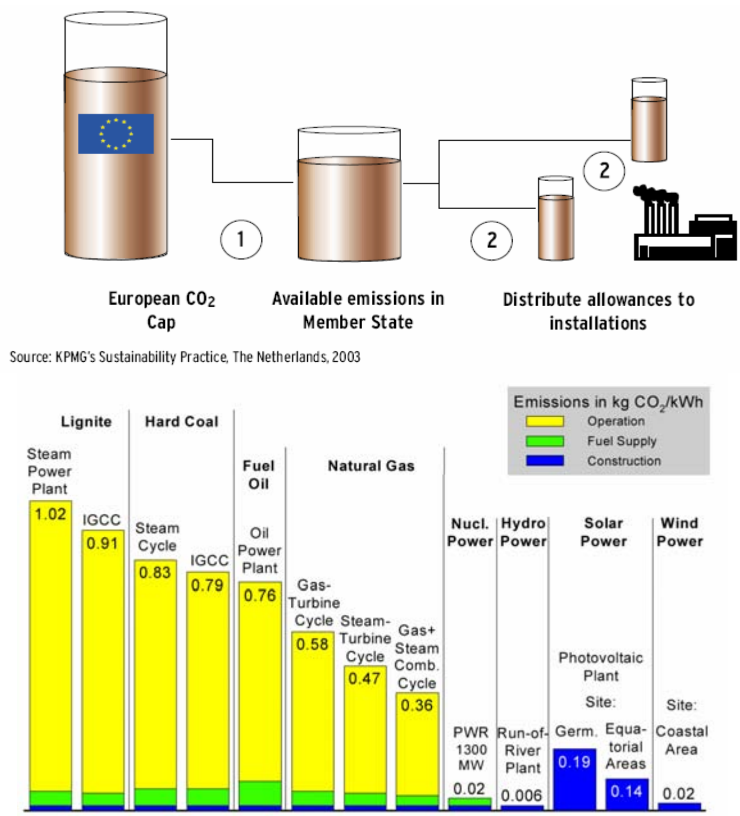

Figure 5. National Allocation Plan and Carbon Dioxyde Emissions per kWh.

Around 55% of emissions covered by EU ETS are allocated to power plants. 10 biggest power companies (RWE, Vattenfall, EoN) are controling 30% of all CO_2 emissions covered by EU ETS [9]. The main influence on energy sector will be through electricity price and new approach with respect to the change of generation costs of peak and baseload units. Prices of electricity in the liberalised power market are increasingly complex and difficult to predict, however CO_2 will now be one of the price factors.

The presence of CO_2 in the electricity price will probably accelerate the tendency for gas to become the preferred fuel in power generation. However, gas production in Europe is not expected to grow as strongly as gas demand in the region. With growing reliance on gas imports, the access to such supply in the long term at attractive conditions is also crucial. However, increased demand would imply increased prices. Most of the potential future gas supply is projected to come from sources located in technically challenging and politically risky environments. The development of new gas supplies and the infrastructure to deliver the commodity to the market will therefore require substantial investments, so the gas consumers would face the prospect of having to pay significantly higher gas prices. Another reason why gas prices might increase is related to the way the gas prices are fixed in long term contracts. Coal and lignite emit twice the amount of CO_2 than gas, which gives additional value to gas. Therefore, because of the new carbon emission constraint, gas suppliers might be inclined to claim the value attributed to the difference in CO_2 emissions between gas and coal. Gas suppliers might include at least part of this additional CO_2 emission value in their gas contracts, thereby increasing their gas prices.

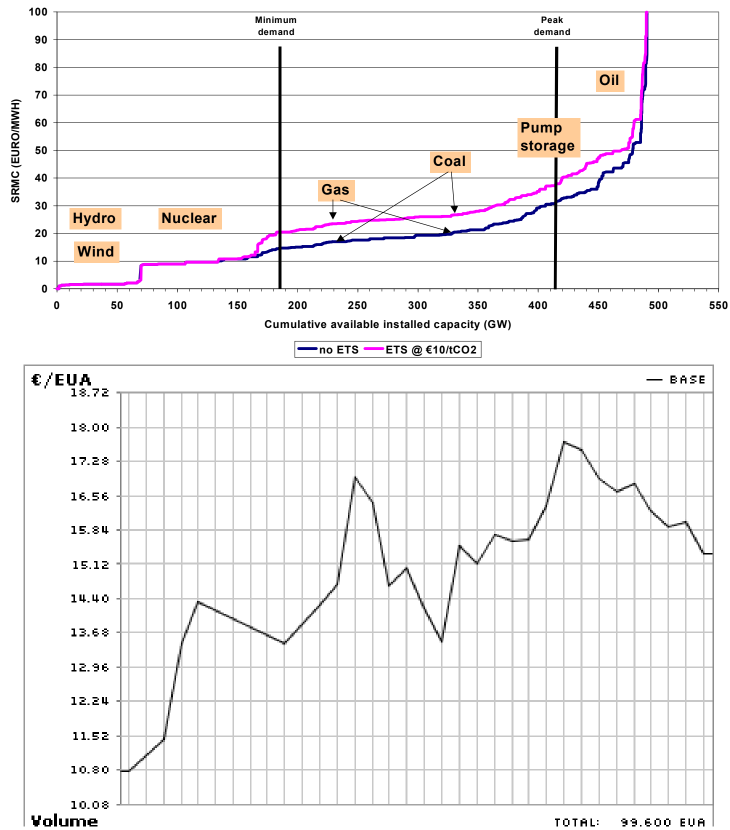

Figure 6. Impact of EU ETS on scheduling of power generation and electricity price.

The carbon "emission allowance" will increase the variable costs for fossil-fuelled power plants and thus its short-run marginal costs since an emission allowance will be needed for each unit of CO_2 produced. Coal accounts for approximately 30% of EU power generation. New technologies that will be developed for zero emission fossil fuel power plants will be CO_2 capture and storage (CCS). The EU Commission has a target cost of capture and storage of below € 20/tonne CO_2. At this price coal plant with CCS and combined cycle gas turbine plant (without CCS) are the cheapest options for producing power. New power plants with CCS technology can be developed by 2015-2020 as well as increased plant efficiency [13].

A whole range of new businesses is emerging in Europe as a result of the EU carbon market: carbon funds, carbon traders, carbon finance specialists, carbon management specialists, carbon auditors and verifiers. Companies and other participants in the market may trade directly with each other or buy and sell via a broker, exchange or any other type of market intermediary that may spring up to take advantage of a new market of significant size. The success of the American SO2/NOx markets is without doubt due to the technology push it created, stimulating the timely introduction of new low emitting technologies. The cost of reducing SO2 emissions under the US scheme, for example, was forecast at from $700 to $1,500 a ton, yet the final market price of rights reflected a reduction cost of $350 a ton [14]. This will also probably be the case with EU ETS. EEX is one of several exchange projects launching emissions contracts. Nordic power exchange Nord Pool has been running futures contracts. A joint venture of IPE and the Chicago Climate Change, ECX, France's Powernext and Austria's EXAA are also planning contracts.

What about new installations? In the first case, Member States may choose to let new entrants buy allowances on the market – in that case, there is no need to reduce the total allocated quantities as set in the preceding step to provide for new entrants. In the second option, Member States could choose to build a reserve of allowances for new entrants. Up to the amount of allowances in the reserve, new entrants would be given a free allocation.

4 Croatian Case and Impacts on Energy Sector

Croatia became a Party to the United Nations Framework Convention on Climate Change (UNFCCC) in 1996 [23], and has signed Kyoto Protocol in 1999. However, due to the specific circumstances Croatia has still not ratified the Protocol.

The main problem regarding the Protocol ratification for Croatia is a very low emissions level in the base year 1990. Namely, according to Kyoto Protocol Croatia has the GHG emissions reduction obligation of 5% below 1990 level in the period 2008 - 2012. The GHG emissions of Croatia in 1990 amount to less than 0,2% of the Protocol Annex I Parties emissions, and the GHG emission per capita amounts to 6.55 $MteqCO_2$ which is one of the lowest among Annex I Parties. This is due because of the great portion of the use of renewable resources in energy production. Namely, 40-60% of electric energy is produced by hydro-plants, 15% of electricity is produced by cogeneration, 15% of electricity needs is covered by nuclear power plant Krško, Slovenia, and the coal is used in only 10% of the electricity production. [24]

The Croatian particular problem raises in the fact that the base year emissions were low because Croatia has been supplied with the energy from the power plants situated in the other ex-Yugoslavia republics, since those republics and Croatia were parts of the same federal state (until 1991 22% of the electricity needs were covered this way) [24]. However, since those power plants are not situated in the territory of Croatia, the emissions from those plants have not been taken into consideration within the baseline determination.

It should be noted as well, that due to the special circumstances during the Homeland War (when overall decrease of economic activities and energy consumption occurred) and the transition to the market economy (which led to the downsizing or abolishment of some, even though there were no many to begin with, energy intensive industries) the GHG emissions have fallen for about 45% in the period 1990-1995. [24]

In the following period the situation changed, and between 1995 and 2001 the GHG emissions rose on average by 3.2% per year. With this pace Kyoto quota will be exceeded in 2005.

Here it is important to stress that one of the main principles of the UNFCCC and Kyoto Protocol is the principle of common but differentiated responsibility of the parties and according to this principle the specific situations and circumstances of a certain party should be evaluated and taken into account.

Based on the above principle and on the fact of very low emissions, for the purpose of baseline determination very unfavourable structure of the emissions source (namely, high portion of renewable energy sources) and of the dependence on the energy import, Croatia is negotiating the increase of the base year emissions level within the UNFCCC implementation authority. In order for Croatia to be able to successfully implement Kyoto Protocol the base year emissions level should be increased by 4,46 million tons eq-CO_2.

In addition to the above Croatia is also 'counting' on the CO_2 sinks inclusion into the emissions calculation. Namely, Croatia is covered by forests in 36% of the territory. According to the UNFCCC CO_2 sinks are to be accounted, namely, taken off the total emissions. The amount to be accounted has not yet been decided for Croatia – this will also play an important role for Croatia's Protocol implementation possibility.

Further negotiations and decision taking on the Croatian issues above is expected on the next session of the UNFCCC implementation authority in June 2005.

One of the reasons why the decision regarding baseline emissions for Croatia was not taken in COP10 in Buenos Aires in December 2004 was that the EU representatives promoted Croatian abandonment of the request and the solving of the matter with the European Commission.

It is possible that this matter be solved within Croatia and EU, and the new EU ETS, if the Commission would grant Croatia to issue as many emissions allowances as would cover the requested and necessary baseline emissions level for Croatia. In this case, Croatia might be able not to exceed Kyoto quota and to participate in EU ETS.

When evaluating the impact of the Kyoto Protocol implementation and emissions trading on Croatian energy sector the basic interest of energy security in Croatia should be taken into account.

In order to ensure electricity supply in Croatia, it is necessary to construct another 2500 MW production facilities until 2020 and to invest into the transmission and distribution facilities.

Strategically it is important to dispose of the electricity production units on ones own territory, as could have been seen in the examples of the recent electricity supply disorders in Europe and North America.

Currently Croatia disposes of 30 power plants in the its territory (21 hydro power plants and 9 thermal power plants) and of 50% of the nuclear power plant Krško in the territory of Slovenia. This means that 2063MW hydro power plant with the average production of 5800 GWh per year and 1956 MW thermal power plants are situated in the territory of Croatia.

The question raises what power production plants are to be built in Croatia having in mind the EU accession and Kyoto Protocol implementation, but also the security of supply needs and general economic situation in the country.

The main advantage of the gas power plants is in rather low investment expenses for the combine gas thermo power plant and in relatively acceptable environmental influence. However, there is a negative side of the gas power plants coin, and that is unsafe long term supply, impossible diversification of the supply route and uncertainty and risk connected to prices in long term.

All negative aspects of the gas come as a positive once regarding coal. Namely the advantages of the coal as a power plant fuel raise in the good conditions regarding long term supply, possibility of a diversification of the supply route and long term stability of the price.

Nuclear fuel is acceptable from the environmental and price point of view. However the nuclear power plants are expensive in construction, and also attract negative public opinion which makes them rather unattractive.

The most attractive possibility are renewables. They are environment friendly, popular and form a firm goal of many energy strategies, as well as Croatian. However, due to rather small capacity and noneconmic features, renewables cannot be accounted for salving of the electricity supply in general.

5 Conclusion

The European Emissions Trading Scheme introduced a business side into the national emissions reduction goals. EU ETS has created a possibility for the installations – companies to actively participate in the trade of CO_2 emissions allowances. Corporate strategy of CO_2 management will include the management of energy, emissions, and of the emissions allowances trade. The sooner the company adjusts and starts participating in the new market the more will it be able to influence the future development of the company in this market. For the electricity undertakings this adjustment includes the change of fuels in power plants.

The first phase of EU ETS will show the liquidity of the European emissions market and will determine the strategy for the second phase for the period from 2007 onwards. However, emissions trading is to be only a part of the general emissions management – energy efficiency support and development of renewable energy resources also form part of this strategy. Other Kyoto Protocol implementation mechanisms, namely joint implementation and clean development mechanism, give additional possibilities to corporate management. These mechanisms also give more options for Croatian possibility of active participation in EU ETS market.

Europe’s plan to control greenhouse gases emissions responsible for global warming will probably lead to higher energy prices and greatly accelerate the shift from coal (including lignite) to gas as the primary fuel used in power plants. The power industry has to respond to the both objectives of energy security and low GHG emissions. Emission trading, and flexible mechanisms, can play useful and essential roles to realise these objectives, if they are based on a well thought and realistic planning of new technology introduction. The option to trade encourages companies to explore innovations that might reduce their emissions. If a company can cut its emissions for a cost lower than the market price for emissions rights, it has an incentive to do so and to sell its excess rights. Since other companies can then buy those rights, their market price falls to the cheapest cost of reducing emissions.

The case of Croatia within the EU ETS needs to be viewed within the special Croatian circumstances discussed in this paper. Croatia is expecting that the baseline emissions level be raised and that CO_2 sinks will play significant role within the emissions reduction requirements for Croatia. It is also expected that the EU Commission will note and evaluate the above circumstances and the important objective of energy security when deciding about the emissions allowances being granted to Croatia and the inclusion of Croatia into the EU emissions market.

Without the change in the baseline emissions level and the treatment by the EU Commission taking into consideration Croatian special situation and very low GHG emissions level, it would be very hard, if not impossible for Croatia to comply with Kyoto Protocol requirements.

In the end it should be noted that by Kyoto Protocol we are fighting climate change and preserving environment under the umbrella of sustainable development.

As the president of the European Commission Jose Manuel Barosso in his concluding speech to the Stakeholder Forum on Sustainable Development in Brussels on 15 April 2005 stated:

“...The recently relaunched Lisbon reform strategy and the Sustainable Development Strategy form key elements in the partnership for prosperity, solidarity and security that is at the heart of the EU's strategic priorities ...Our is an integrated vision – encompassing the economic, social and environmental dimensions of the Union’’ [25]

In the preamble (5) of the 2003/87/EC Directive it is stated that "This Directive aims to contribute to fulfilling the commitments of the European Community and its Member States more effectively, through an efficient European market in greenhouse gas emission allowances, with the least possible diminution of economic development and employment."[4]

We believe that Croatia and its installations which will obtain emissions allowances should be given equal opportunities in sustainable development as the other members to the EU ETS. For this it is essential that, having in mind the UNFCCC principle of joint but differentiated responsibility and the aim of the EC Directive on GHG emissions trading to, the special circumstances affecting Croatia be awarded special treatment.

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REGULATING ANIMAL MANURE TO REDUCE POLLUTION AND ENSURE SUSTAINABLE PRACTICES*

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Economies of scale have led to the production of animals at large facilities concentrated in selected regions. Due in part to this concentration, water contamination by animal manure has become a major issue. In the United States, regulatory provisions are being employed to reduce potential contamination problems. One limitation of the regulations is that they tend to give minimal encouragement for using manure as a production input. This paper suggests three strategies to encourage sustainability by more careful use of manure for production inputs rather than disposing it as a waste product.

1 Introduction

Concerns about water pollution in the United States from animal feeding operations that confine animals has led to renewed governmental efforts to regulate animal production under the U.S. Clean Water Act. In 2003, the U.S. Environmental Protection Agency (EPA) adopted new regulations for concentrated animal feeding operations (CAFOs), the largest producers whose manure production might be expected to create an environmental problem [1]. An operation meeting the definition of a CAFO with a discharge of pollutants needs to secure a National Pollutant Discharge Elimination System permit [1]. As livestock production continues to shift to larger operations [2], more CAFOs will be regulated under federal law and there should be less water pollution from these operations.

However, only about 4.5 percent of animal feeding operations are CAFOs with discharges regulated under federal law. The U.S. Department of Agriculture reports that over 234,000 animal operations are not regulated by the federal provisions [2]. Moreover, approximately 200 million tons manure produced at animal feeding operations are not regulated under our federal point-source permitting regulations [2]. Nonpoint-source pollution is the leading cause of the impairment of assessed rivers and lakes with agriculture being the most wide-spread source [3].

Producers and regulatory agencies are pursuing actions to forestall environmental damage. Three major governmental strategies can be identified that address mechanisms for treating manure and animal waste as a production input rather than a production byproduct for disposal. The first involves agronomic rate application regulations for nitrogen and phosphorus. State regulations may impose mandatory guidelines limiting the

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amounts of animal manure that may be applied to lands. The second strategy involves directives that enhance the absorption of manure into the ground for use by crops. Directives on the timing and method of application of manure to fields can affect the usability of nutrients. Lagoon design and use of nutrients offer a third strategy to enhance production by addressing nutrient losses through seepage or lagoon failure.

2 The Regulation of CAFOs

Under the U.S. Clean Water Act, the federal EPA has the authority to regulate discharges of animal wastes from point sources. Effluent guidelines for "Feedlots Point Source Category" are enumerated in the Code of Federal Regulations for large animal operations [4]. The EPA is authorized to oversee the permit program in each state in the absence of an approved state program. However, most states have been delegated authority to implement and administer the federal permit provisions so that state regulatory agencies are responsible for issuing permits.

All CAFOs with discharges need permits [5], unless the discharge from a field falls within the definition of an agricultural stormwater discharge. The Clean Water Act expressly defines point sources to exclude agricultural stormwater [6]. Agricultural stormwater is defined by federal rules as any "precipitation-related discharge of manure, litter, or process wastewater from land areas under the control of a CAFO" where the manure, litter or process wastewater has otherwise been applied in accordance with site specific nutrient management practices that ensure appropriate agricultural utilization [4]. Thus, agricultural stormwater is not regulated by the act.

Separate federal regulatory provisions exist for four categories of animals: horses and sheep; ducks; dairy cows and cattle other than veal calves; and swine, poultry, and veal calves [4]. Different technological requirements are set for CAFO production areas, CAFO land application areas, and for new sources.

2.1. *Pollutants*

Four categories of pollutants are discussed in the regulations: manure, litter, process wastewater, and overflows. Under the CAFO regulations, permits apply to all manure, litter, and process wastewater generated by animals or the production of animals at an operation. Manure is defined to cover the expected wastes and bedding materials. Litter is not defined but means poultry droppings mixed with shavings or other absorbent material. Process wastewater includes spillage or overflow from watering systems, washing, cleaning, or flushing pens, barns, manure pits and any water that comes into contact with any raw materials, products, or byproducts [4]. By defining process wastewater to cover these uses of water and placing process wastewater within the regulated pollutants, the CAFO regulations govern waters used at a CAFO in the same manner as animal waste.

Overflow is defined to cover the discharge of manure or process wastewater due to the inability of a storage structure to contain the material. Overflow exceptions based on chronic or catastrophic rainfall events allow discharges in limited situations. For example, CAFOs with dairy cows or beef cattle cannot have any discharge of manure, litter, or process wastewater pollutants from the production area. However, if precipitation from an unusual rainfall event causes an overflow of manure, litter, or process wastewater, pollutants in the overflow may be discharged into U.S. waters provided certain conditions are met.

2.2. *Production and Land Application Areas*

The permit requirements for discharges from CAFOs apply with respect to animals in confinement at a facility and all manure, litter, and process wastewater generated by those animals or the production of those animals. The federal regulations define production areas to include animal confinement areas, manure storage areas, raw materials storage areas, and waste containment areas. Further provisions define each of the four enumerated areas. Production areas include feed silos, silage bunkers, bedding materials, berms, egg washing, egg processing, and mortality areas.

A separate definition is prescribed for a land application area. It is defined as land under the control of an animal feeding operation owner or operator to which manure, litter, or process wastewater from the production area is or may be applied. Thus, land application areas are treated differently from production areas. Whereas permit requirements apply to the physical areas of production, they also apply to unauthorized discharges occurring at land application areas. The regulations provide that except for agricultural stormwater, discharges of manure, litter, or process wastewater on lands under the control of a CAFO are subject to permit requirements.

2.3. *Field Applications of Wastes*

For large CAFOs that apply manure, litter, and process wastewater to fields, special land application guidelines apply [4]. These CAFOs are required to prepare and implement nutrient management plans based upon a field-specific assessment of the potential for nitrogen and phosphorus transport from the field. Permittees must use technical standards in determining application rates for manure, litter, and process wastewater applied to land that minimize the movement of nitrogen and phosphorus to surface waters.

The regulatory guidelines also establish setback requirements for the application of manure, litter, and process wastewater to minimize opportunities for discharges that would impair water quality. Regulated CAFOs cannot apply these materials within 100 feet of any down-gradient surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters An alternative compliance measure using a 35-foot vegetated buffer is possible [4]. For other situations, a CAFO may be able to demonstrate to the permitting authority that a setback or vegetated buffer can be reduced or even is unnecessary.

2.4. *Insufficient Nutrient Management Oversight*

The U.S. Department of Agriculture considered applying nutrient management standards to all animal feeding operations and estimated it would impose costs of more than $2 billion on the livestock industry [2]. Because of these costs, the final federal regulations omitted a requirement that nutrient management plans be included in permits. In *Waterkeeper Allliance, Inc. v. EPA* [5], a U.S. Circuit Court of Appeals has found that this omission is in error. The court has vacated selected provisions of the federal CAFO regulations and remanded other aspects to the EPA for further clarification and analysis.

The *Waterkeeper Alliance* decision affects the permitting of CAFOs. The finding by the court that nutrient management plans are part of an NPDES permit application increases the need for state administrative oversight. The court's ruling that there is no duty for an owner or operator of a CAFO to apply for a permit if the CAFO does not discharge pollutants is expected to reduce the numbers of CAFOs that must submit permit applications. The decision that the EPA can regulate land application discharges by CAFOs, except those qualifying as agricultural stormwater discharges, means that CAFOs need to be concerned about runoff from the application of manure, litter, and process wastewater.

3. Moving to Sustainable Practices

Limitations with the regulation of CAFOs and the fact that the federal CAFO regulations do not regulate much of the manure being produced by animals suggests that additional efforts to provide protection to water resources are needed [7]. Governments might offer more encouragement for the use of manure as a production input rather than treating it as a production byproduct. The distinction is that current regulations tend to view the disposal of manure as a waste byproduct, omitting consideration of ways to enhance its use as a fertilizer for crop production.

Manure supplies nutrients and organic matter, augments the water-holding capacity, and increases a soil's fertility [8]. A few states have legislation that provide for the application of manure to land as a recommended agronomic practice [9]. These regulatory provisions delineate criteria to advance sustainability. By incorporating sustainable ideas in regulations governing animal wastes, further encouragement might be given to help producers recycle nutrients from manure as a production input [10].

Three major objectives can be incorporated into nutrient and manure management programs: (1) to help protect water quality, (2) to reduce conflicts with others, and (3) to enhance crop performance. While governmental regulations often address the first two objectives and provide operators discretion in developing practices and implementing technology to reduce nutrient contamination, further efforts to enhance crop performance through the application of agronomic practices are possible. Both excessive quantities of animal wastes from CAFOs and large quantities of unregulated manure suggest that governments can advance the more careful use of this byproduct.

3.1. *Rate Application Regulations*

Problems with the overapplication of manure and the application of liquid manure through irrigation systems are propelling states to regulate these activities. Animal manure placed on fields or applied as spray irrigation may percolate through soils to contaminate underlying aquifers. A survey of hog farmers in North Carolina revealed that only 40% had tested the content of their waste before applying it to the land [11]. After investigating 1,595 drinking water wells located on property next to hog and poultry production facilities, 10.2% of the wells were found to have nitrate levels above the current drinking water standard of 10 parts per million. These wells thereby show an environmental problem.

In an attempt to reduce pollution from manure applications, 34 states have enacted regulations requiring wastes from CAFOs be applied to land at agronomic rates [12]. To comply with the application requirements, farmers employ a nutrient and manure management program. Farmers calculate the nutrients in the manure and in the soil to ascertain a crop's need for additional nutrients. The regulations prohibit the application of manure to fields where amounts of the listed nutrient are already present in sufficient quantities for the crop being grown. Nitrogen may be the only listed nutrient, or a state regulation may list both nitrogen and phosphorus.

More widespread application of rate regulations is possible [6]. There is a need to use new technology in more accurately calculating and measuring the amount of nitrogen in manure applications that will be available to plants. Although soil and manure testing can provide rough calculations regarding amounts of nitrogen, they do not reflect the mineralization of nitrogen nor atmospheric losses. When a government has a rate regulation, farmers are required to forego applying excessive amounts of listed nutrients that can contribute to unnecessary water contamination. What this usually means for the application of manure is that a farmer can only apply a quantity required to reach the recommended amount of phosphorus. For nitrogen requirements, an appropriate commercial fertilizer should be used to alleviate the deficiencies and provide for optimal crop production.

3.2. *Enhancing Absorption of Nutrients*

Considerable efforts have been made to assist CAFO owners and operators in taking appropriate actions to avoid the overapplication of surplus nutrients from animal waste. State extension services have helped farmers by making information available to them on nutrient management plans and in providing testing services. One important development has been recognition that training is required for persons in charge of disposing of manure. State legislatures have adopted provisions requiring training for animal waste management system operators [13]. Yet training efforts may need to be augmented to address the coordination of reliable sampling and testing results with nutrient applications. Many farmers need more training on how to understand and evaluate nutrient testing results.

Some state nutrient and manure management provisions delineate practices that foster the use of nutrients for crop production. Several ideas may be highlighted. Minnesota enunciates a general prohibition against application of manure that would cause contaminated runoff [14]. On lands prone to flooding, manure application through injection or incorporation into the soil may be required. Similar provisions may apply to steeply sloping cropland. To minimize runoff of manure, some northern states limit the application of manure on snow-covered ground [8]. Another provision may prohibit manure application in road ditches [14].

Obviously, CAFO producers would prefer there be no regulations. However, because of widespread pollution of surface waters, both regulatory and voluntary efforts may be needed. Greater care needs to coordinate rate applications with absorption.

3.3. *Lagoons*

Contamination of waters by lagoon collapses has spurred greater regulations of lagoon design and maintenance [15]. Recently, design requirements have been added by many states. Because lagoons have gotten larger, corresponding to larger animal production operations, governments have mandated design specifications so that lagoons are less likely to fail. Moreover, lagoons are also being precluded from flood plains and environmentally sensitive locations [13]. Governments are incorporating scientific information into lagoon regulations to help safeguard water quality.

Governmental requirements that lagoons be designed by professionals are important. Another regulatory feature involves detailed rules prescribing liner requirements [16]. Other requirements may require a lagoon capacity determined by analyzing the volume expected to be generated over a designated number of days [16].

For larger operators and operators using spray irrigation fields for liquid animal wastes, the installation of groundwater monitoring wells might provide greater assurance that there is not a contamination problem. In Georgia, the rules on monitoring wells apply to swine CAFOs with 1001—3000 animal units [13]. The Illinois regulations require at least three monitoring wells for some lagoons [8]. Other responses address the location of lagoons, including a prohibition in flood plains. While the 100-year flood plain delineated by a Georgia rule may be unduly restrictive, the 10-year flood plain restriction in Illinois may not provide the protection desired.

Another state regulatory response to lagoons is the delineation of provisions concerning inspection. Two types of inspection are important: inspection of the construction of a lagoon and inspection of subsequent operations. Regulations can require the inspection of new lagoons at least once during preconstruction, construction, or a post-construction phase, as provided by an Illinois regulation [16]. Other provisions regarding the professional specifications for lagoons may incorporate inspection requirements for new lagoons.

A weightier question may involve the inspection of existing lagoons. Inferior design standards and opportunities for maintenance lapses mean that there is a need to inspect older lagoons. Most animal waste lagoons that fail and cause significant environmental damages were constructed prior to the design standards in use today. The most practical way to address the potential shortcomings of these older lagoons is embarking on a state monitoring program involving inspections.

With lagoon design being regulated, another issue involves the use of the liquid and solid wastes from the lagoon. Application of these materials can be governed by the rate application regulations and the ideas for enhancing absorption of nutrients.

4 Conclusion

In the United States, federal and state governments have enacted new legislation and regulatory provisions to respond to problems created by concentrated animal production, with an emphasis on eliminating water pollution. Individual state governments in the U.S. have enacted additional provisions to address public concerns about water pollution from animal manure. Regulatory provisions concerning the certification of operators and facilities, design and inspection of lagoons, and accountability requirements delineate practices being employed to reduce potential contamination problems.

However, agricultural producers and governments might do more to safeguard water quality. Encouragement of practices that use animal waste as production inputs can help eliminate pollution. Because preventing pollutants from entering waters involves costs, governments enact legislative and regulatory provisions to preclude contamination. Regulations governing animal feeding operations in the United States show mechanisms that can encourage sustainability and diminish pollution.

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HEATING PLANT AIR POLLUTION REDUCTION: THE CASE OF KRAGUJEVAC TOWN

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Industrial production processes still account for a considerable share of the overall pollution and have serious negative impact on the environment. This paper describes the air pollution problems in Kragujevac and its surroundings that come from coal-fired heating plant placed in the vicinity of the downtown area and represents potentially the largest atmospheric pollutant for the town and its surroundings. In the assessment of ambient air quality, the levels of harmful air pollutants (emission and imission of the sulphur dioxide, nitrogen dioxide) and settling of fine ash particles are analyzed. The wind rouses map of the potential endangered areas for Kragujevac and its surroundings are presented in this paper. The aim of this research is propose the necessary measures for reduction of air pollution in the town of Kragujevac and its surroundings on the basis of the obtained results.

1 Introduction

Depending on used fuel type, heat production in the heating plant, the industrial power-plant and the thermal power-plant influence more or less on the environmental pollution. Emission of the harmful (polluting) substances from the thermal power-plant includes following items: flue gases, dust, slag, ash and wastewater. The coal-fired power plant and heating–plant represent the largest atmospheric pollutants in urban areas and it's surroundings and the special attention would be paid to protection and maintenance of the air quality from the following harmful substances: SO_2, NO_x and solid particles of ash. The influences of the thermal-power plant and the heating-plant are multiple, with intensive and more or less negative influence to ecological system as well as reflection of bad influence far from the area of the industrial objects.

In our case the heating-plant is placed in the vicinity of the down-town area and represents potentially the largest atmospheric pollutant for the town and its surroundings. It's a real threat to the local public health.

It has been noted that this paper is occupied with the air pollutant problems, establishment of the limit value emission of the effluents (SO_2, NO_x) and settling of the fine ash particles for the town and it's surroundings. Dispersion of these pollutants depends on the following parameters: quality of the heating plant burned fuel, state of the equipment and leading of the process in the boiler, useful climatic data, stack height and kinetics energy of the outlet stack flue gases.

2 The basic technical characteristics of the plant

The heating-plant is situated in the central zone of the town of Kragujevac and represents the largest part of the resident district heating with 306 MW of the total installed power.

The plant produced of the heating power consists of the five boiler units that are connected in the system (K1, K2, K3, K4 and K5). They have different constructions, capacities and different prime (power) fuels. The gas and coal as prime fuel are used. The basic technical parameters of the boiler units are shown in the Table 1.

Table 1. The basic technical parameters of the boiler units ([a]estimate value).

Boiler	Installed power (MW)	Designed parameters of the steam			Working parameters of the steam			Efficiency		Prime fuel	
		p_p	t_p	m_p	p_r	t_r	m_r	η_p	η_r^a	-	-
		bar	°C	t	bar	°C	t	-	-	-	-
K1	31.5	37	450	-	30	450	-	0.95	≈0.9	gas	
K2	31.5	37	450	-	30	450	-	0.95	≈0.9	gas	
K3	63.5	37	450	80	30	450	80	0.85	≈0.8	coal	
K4	63.5	37	450	80	30	450	80	0.85	≈0.8	coal	
K5	115	37	450	150	25	450	80	0.85	-	coal	

3 Calculate of imission SO_2, Nox (in form of NO_2) and particle of fly ashes

3.1. Meteorological conditions

Meteorological date needed for calculation are obtained from the Serbian Republic Hydro-Meteorological Bureau [1, 2]. The date are consisted of the following results: measuring of temperature per hour, velocity and direction of wind (16 meteorological directions) as well as values of daily insolation, cloudiness and precipitation for determined time period.

Collected measuring date show on average wind velocity in an hour. The directions wind blowing is determined by angle of incidence of 22.5°; the angle that belongs to each of 16 directions (360°/16=22.5°). The axis of spreading effluents out of stack is placed in wind direction and in certain angle of the direction (22.5°) with the vertex in source of emission (top the stack).

The heating period in Serbia lasts from the middle of October to the middle of April and the heating-plant works 15 hours daily (from 6 to 21 hour), so statistical analysis of obtained date for working hours of heating-plant per month and in heating period of 2002/2003 is realized. The winds are grouped according to the directions of blowing (16 directions) and the velocity intervals (in ranges of 1 m/s), too. The hours of wind blowing by directions and by intensity of wind during the work of the heating-plant in each month are also summarized. In that way the date that are used for calculating the particular monthly wind rouses map have influence to the directing and spreading of effluents from stack of the heating-plant.

In this paper, particular wind rouses map for December 2002. is presented graphically, that is potential endangered areas by hours of wind blow in certain direction are shown in the topographic map of Kragujevac and it's surroundings (Figure 1). Based on the graph, Figure1, the south-east wind was the most influence in December 2002. The wind endangered the north-west area of town in regard to the heating plant. However, the west winds were hazardous for the east part of downtown.

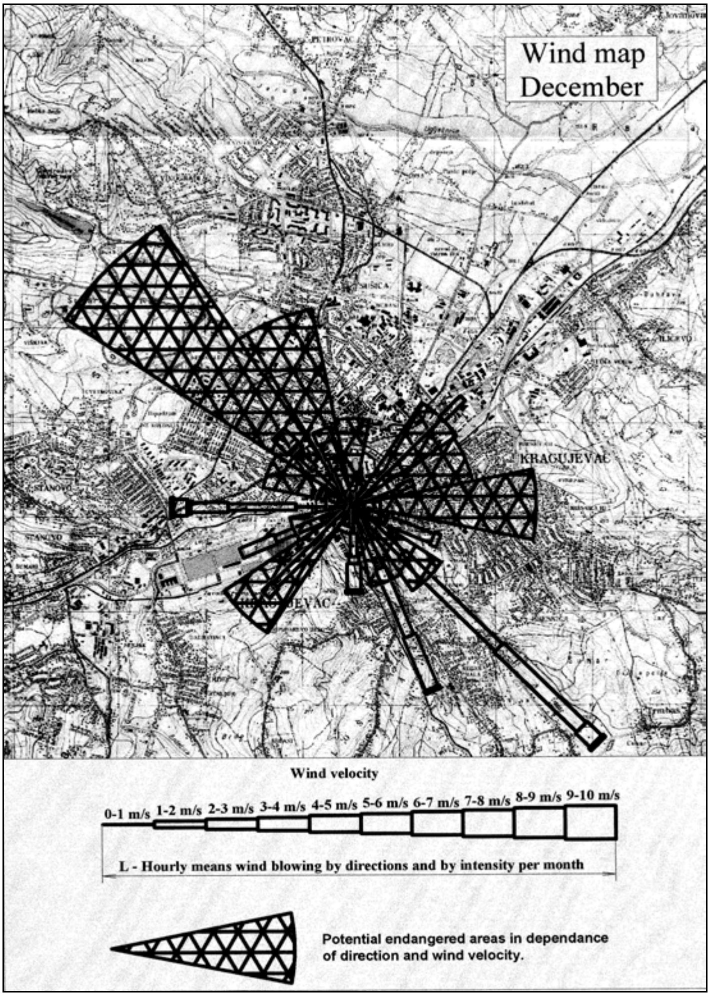

Figure 1. Wind rouses map for December 2002, λ= 1.55.

3.2. Calculation of effluent imissions

Diffusion of gaseous effluents (SO_2, and NO_2) is determined on basis *Gaussian* equation of spreading. The equation, according to equal possibilities of plum axis position in the range of the angle 22.5° for the ground level concentrations gets following form:

$$q = [Q/ (\pi\sigma_y\sigma_z U)] \exp [-0,5 (H/\sigma_z)^2], \quad (1)$$

where are: q – concentration of gas in the area of town – imission in mg/m^3; Q – gas emission in the source in mg/s, H – real stack height in m and U – average wind velocity in m/s.

Real stack height is the sum of the stack height and height of the plume rise. The height of the plume rise is calculated on the basis of velocity and temperature of outlet gases, wind velocity and stability class. The diffusion parameters depend on distance downwind and stability class. Since the heating-plant with two stacks is placed in downtown (near by center of urban area), *Mc Elroy's* correlation for an urban location with the sampling time of 1 hour is used in calculation of plum spreading and imission as well as in determination of diffusion parameters [3].

The imission calculation of SO_2, NOx (in form of NO_2) and particles of fly ashes in the areas from the source down the wind (stacks 1 and 2 of the heating plant) is realized for each wind direction in particulate mouth of the heating period 2002/2003. All velocity ranges and corresponding stability class, occurred in that direction for defined duration, are used in the calculation. Imissions on the positions e.t (that is) on defined distances from the stack to down the wind are determined by superposition of imission produced in imissions of the both stack. The imissions of graduate increasing of distance of initial spot (mean distance of stack axes), downwind in particular direction, with permanent comparation imission with the critical values of imission (according to regulations), are calculated by verified math model in the Institute property [4, 5].

If the calculated value of imission at certain distance from the source exceed the critical value, that distance would be remembered as the first limited value in the area with the increased concentration. In additional calculation, the second further limited value is determined. This is the value when the imission stop to be higher than the critical concentration value. Every meteorological situation (wind velocity and appropriate stability class) that is occurred in some direction for a particular hours (duration) when the excess of a critical concentration values in the limited area is happened, contribute to determination of exceed concentration area in the certain direction with more than 20, 40, 60 hours etc. The calculations are done for each month of heating-plant work in the heating period 2002/2003, and for excess air coefficients in boilers λ= 1.25, λ= 1.55, λ= 2.0.

The values of critical concentration for SO_2 correspond to the hourly means regulated limitations:

- 0.35 mg/m^3 for urban areas, and
- 0.15 mg/m^3 for rural areas and rarely populated areas.

The values of critical concentration for NO_2 correspond to the hourly means regulated limitations:

- 0.15 mg/m^3 for urban areas,
- 0.085 mg/m^3 for rural areas and rarely populated areas.

The calculations are carried out for SO_2 and NO_2 and for the both critical values of concentrations with the aim to determine whether that exceeds of higher limited values (for urban areas) are happened or the lower limited values (for rural area) are almost exceeded.

In Figures 2 and 3, the topographic map of Kragujevac, the areas with imission of SO_2 and NO_2 over of 20, 40, and 60 hours above the permit limited value (KI), for calculated air excess value of λ= 1.55, are shown for December 2002.

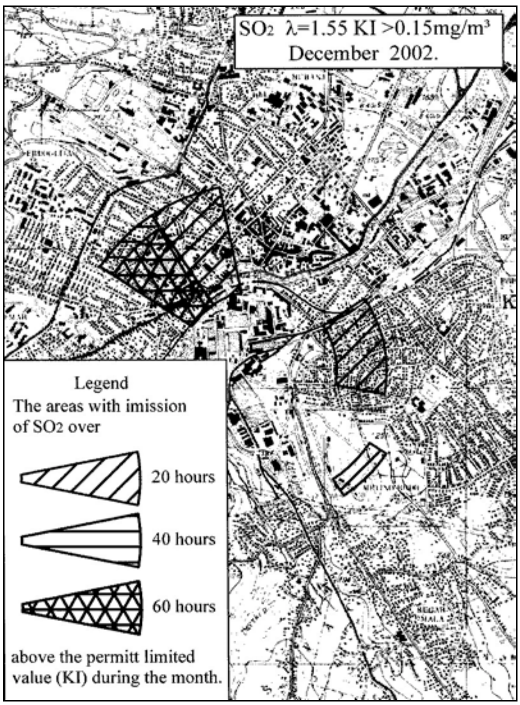

Figure 2. The areas with imission of SO_2 above the lower permitted critical value (KI>0.15 mg/m^3).

On the basis of calculating values for imission of SO_2 (Figure 2) in December 2002., the area with increased concentration of SO_2, over of 60 hours, and above lower permitted critical value (KI>0.15 mg/m^3), covered north-west part of urban zone. The polluted area with over of 20 hours is located the east and north part of town.

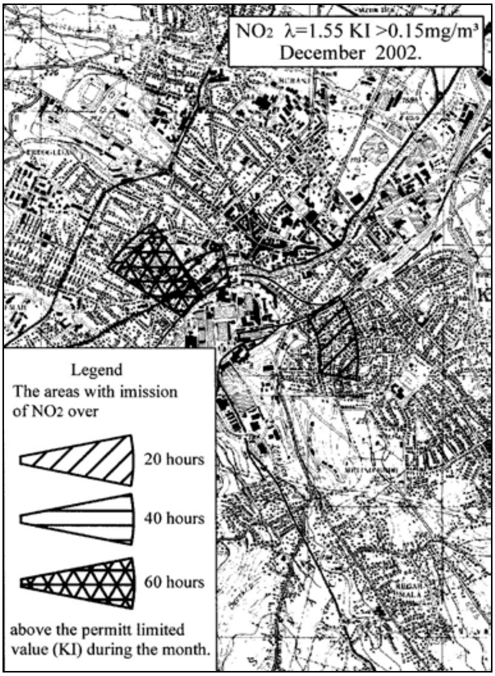

Figure 3. The areas with imission of NO_2 above the lower permitted critical value (KI>0.15 mg/m^3).

On the basis of calculating values for imission of NO_2 (Figure 3) in December 2002., the most endangered area is situated on the north-west of the heating-plant (over of lower permitted critical value (KI) more than 60 hours). Also, endangered areas (more than 20 hours over the KI) were in north-east and south–west part of town.

For calculation of fly ashes particles spreading out of heating plant stack it should proceed from the date that electrostatics precipitators of unit boilers (K3, K4, K5) have efficiency between 92.2-92.5%.

The particles that are lived the stack with the velocity of outlet effluent and by the influence of wind, turn to direction of wind blow while they are falling down toward the ground under the gravitation with velocity which depends on particle diameter, it's density and viscosity of ambient air (*Stokes low*). For the particles with the density more than two times of the water density, velocity of settling is:

$$V(m/s) = 0{,}605\ D^2/10^4. \tag{2}$$

Starting of source particulates rate at the outlet of stack, percented interval of particle diameters in total imission and wind velocity, boundaries of settling area are determined.

Critical values particle ash concentration correspond to regulated limitations:

- 450 mg/m^2/day for urban areas, and
- 300 mg/m^2/day for rural areas.

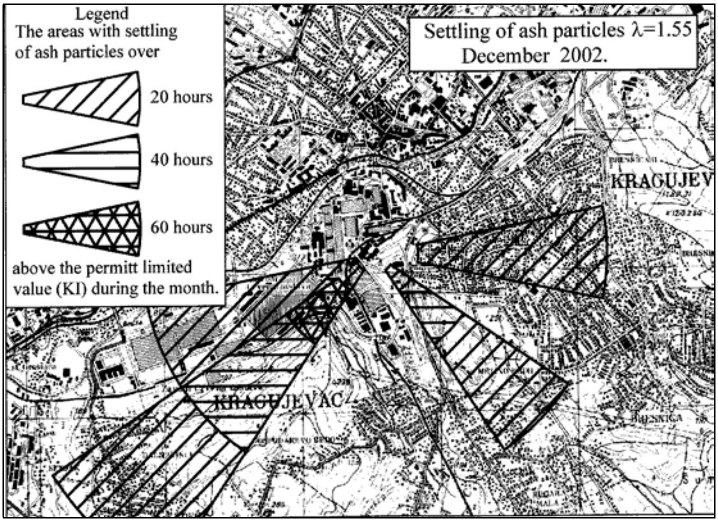

Figure 4. The areas in the town with settling of ash particles.

In Figure 4, the topographic map of Kragujevac the areas of ash particles settling are presented for December 2002, and λ= 1.55. The calculation of ash particles spreading shows that the town was endangered by the particles settling in three directions: maximum in the rarely populated area around the industrial zone of the heating-plant, in east and south-east part of downtown.

4 Conclusions

Spreading of harmful substances in the vicinity of the heating plant in Kragujevac is determined. It has done for basic polluters (SO_2, and NO_2 and fly ash particles) and every month of the heating period (2002/2003 year), based on the technical data of the heating-plant, composition and quality of used fuel and meteorological data by the usage of verified math model. Results of calculation for December 2002 and excess air value of λ=1.55 are presented in this paper. On the basis of the results of calculation, following conclusion could be drawn:

1. The areas with increased concentration of SO_2 for over of 20 hours, above lower permitted critical value (KI>0.15 mg/m^3) in low (grounded) layers of air, but not exceeded the upper permitted critical value (KI>0.35 mg/m^3) are existed. With increase of excess air value in boilers and with increase of the outlet stack effluents velocity, number and range of the endangered areas (with periodical concentration above 0.15 mg/m^3) decrease to certain degree. However, increase of the excess air value in boiler has negative influence on efficiency of the boiler and decrease the electrostatic precipitators work.
2. The areas with NO_2 concentrations above regulated limitations and with more hours in low layers of air occur frequently (in comparison with SO_2 pollution) at lower values of excess air. It happened because the nitrogen oxides appeared as the result

of combustion in all boilers and regulated limitations are stricter for NO_2 imission (0.085 mg/m^3 to 0.15 mg/m^3). All that above mentioned about excess air in boiler could be also applied for consideration of NO_2, but the higher values of excess air reduce the temperature in furnace and, therefore emission NO_2 is reduced.

3. The areas in the town with settling of ashes particles above the regulated limitations, when the electrostatic precipitator of unit boiler efficiency is over 99.2% and estimated grain size distribution of the different diameter ashes (2.5% of particles with diameters range of 20 μm and 50 μm) do not exist.

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ENVIRONMENT MANAGEMENT

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ENVIRONMENTAL SUSTAINABILITY MEASURED THROUGH SOCIAL AND ENVIRONMENTAL RESPONSIBILITY

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This paper has the objective of analyzing the environmental behaviour of one hundred and fifty three potentially polluting Portuguese industries, through an empirical approach based on a market research. An inquiry with twenty two questions is the basis of the research, which methodology applies statistic methods, such as descriptive and factor analysis to find out the strategic factors of environmental responsibility that measures and contributes to sustainability. There are five strategic factors or dimensions: ethics and human resources, marketing, financial, quality, and production.

1 Introduction

Globalization created new chances and challenges to companies, but also increased their organizational complexity. In fact, sustainability depends on managers' decisions that are based on strategic planning and managerial resources.

An ecological accident is easier to be accepted by the shareholders of the company than by the members of the community that suffered the effects of the environmental accident. Sustainability is correlated with environmental and social responsibility, which is demonstrated through the internalization of externalities, meaning the registration of environmental facts on the financial statements.

At present companies live in competitive markets, where the importance of their image and reputation has an increasing prominent role, due to the social and environmental pressures. People that suffers the bad influence of environmental pollution, divulge it. However, these effects should be reported in the company financial statements according to international accounting standards [1-3]. Environmental challenges are changing from being purely technical or financial oriented to encompass a spectrum of new laws and directives, which are influenced by public opinion and ecological lobbies. Actually, the environmental considerations transcend the perspective of the corporate policy, since stakeholders (customers, suppliers, local and central government) play also an important role [4-6].

Several factors contribute to the company's evolution on the conception of its social and environmental responsibility, such as [2-6]:

- Citizens, consumers, public authorities and investors have new concerns and expectations facing the environment.
- The social criteria that influences strongly and increasingly the individual and institutional decisions on environmental investment.
- The increasing concern facing the damages caused on environment, namely by industrial activities.
- The transparency in company activities is due not only to the media but also to information and communication technologies [7,8].

Company's social responsibility implies an ethic management to stakeholders, especially to workers and families, suppliers, customers and consumers, investors, community and society.

The present research was based on an inquiry with twenty two questions addressed to 580 Portuguese companies belonging to potentially polluting activity sectors. This research intends to evaluate and analyse the environmental strategies implemented by companies, which are the foundation for their environmental responsibility and consequently to measure the environmental sustainability.

2 Market Study on Potentially Polluting Portuguese Companies

The inquiry aims to evaluate the environmental responsibility of Portuguese companies that belong to several activity sectors. The survey's questions are based on the field experience that the authors have as consultants and researchers in this area and on the results obtained during a brainstorming session. The panel had ten top managers that worked in industrial companies. They decided about the four company characteristics and the eighteen questions on environmental strategies. The same panel validated the survey questionnaire before sending it by mail and e-mail, to 580 top managers of potentially polluting Portuguese industries, in January 2005 [9]. Special attention was given to the total number of questions, in order to maximize the number of answers without affecting the global information to gather.

In order to calculate the size (n) of the adequate sample of a finite population that guarantees a confidence level (λ) and a precision level (D) for the population proportion (p), the following expression was used [7,10]:

$$n = \frac{p \times (1-p)}{\left[D/(z_{\alpha/2})\right]^2 + \left[p \times (1-p)\right]/N} \,. \tag{1}$$

For a precision level D=±5% and a confidence level λ=95%, the normal distribution has the value $z_{\alpha/2}$=1.96. In the most pessimist hypothesis, where the dispersion is maximum, the proportion is p=0.5. For this value the sample size should be n=150 surveys, however 161 answers were received and 153 were valid. The database built with the valid information was analyzed through the Statistical Program for Social Sciences - SPSS 13.0, using statistic methods, such as descriptive analysis and factor analysis (principal components).

The company characteristics under research are seven for the activity, three for the size, six for the location, and two for the head office nationality. Table 1 shows the characteristics of companies in percentage.

Table 1. Characteristics of companies.

Characteristics of companies		%
Activity	Oil	4
	Paint, ink, polish, lacquer	12
	Plastic	16
	Paper	12
	Tanning	30
	Cement	2
	Cattle	24
Size	Large enterprise	12
	Medium enterprise	32
	Small enterprise	56
Location	North	26
	Centre	20
	Lisbon & Tagus Valley	42
	Alentejo	6
	Algarve	6
	Madeira & Açores	0
Head Office Nationality	Portuguese	78
	Other country	22

Thus, 54% are tanning and cattle companies, 56% are small companies, 42% are located in Lisbon and Tagus Valley region, and 78% are Portuguese companies.

Table 2 presents the mean value (x_m) and standard deviation (s) for the following environmental strategies, using the Likert scale with five levels (1: never, 2: seldom, 3: sometimes, 4: often and 5: always).

The environmental strategy "company has environmental concerns" (x_m=4.4, s=0.5) has the maximum mean value, being followed by "company implements environmental responsibility" (x_m=3.8, s=1.0).

However, "company has anti-pollution production processes" (x_m=1.5, s=0.8) and "company has provisions for future environmental risks" (x_m=1.5, s=1.0), both get the minimum mean value, being followed by "company has environmental investments" (x_m=2.1, s=1.4) and "company discloses environmental facts in balance sheet" (x_m=2.1, s=1.4).

Table 2. Descriptive statistics of environmental strategies.

	Environmental strategies	Mean (x_m)	Std. Dv. (s)
1	Company has environmental concerns	4.4	0.5
2	Company implements environmental responsibility	3.8	1.0
3	Environmental responsibility is due to influence of stakeholders	3.1	0,7
4	Environmental responsibility is a competitive advantage	3.0	1.1
5	Environmental responsibility improves company's image	3.0	1.0
6	Company has concerns with environmental workers' training	3.3	1.4
7	Company's performance depends on environmental training	3.5	1.3
8	Company has anti-pollution production processes	1.5	0.8
9	Company has environmental insurances	3.6	1.3
10	Company does not cause polluting accidents	3.3	1.4
11	Company is certified according to ISO 14000	2.5	1.1
12	Company has environmental investments	2.1	1.4
13	Company produces green products	2.5	1.5
14	ISO 14000 certification signifies environmental responsibility	2.2	1.7
15	Company discloses environmental facts in balance sheet	2.1	1.4
16	Company discloses environmental facts in the annex of balance sheet	2.4	1.4
17	Company has provisions for future environmental risks	1.5	1.0
18	The annual management report has references of environmental facts	2.7	1.6
	Mean value	2.8	1.2

The maximum standard deviation appears on “ISO 14000 certification signifies environmental responsibility” (x_m=2.2, s=1.7) and it signifies that the answers are not consensual. “The annual management report has references of environmental facts” (x_m=2.7, s=1.6) has also answers with large variations.

On the other hand, the consensus is relevant in “company has environmental concerns” (x_m=4.4, s=0.5) and is followed by “environmental responsibility is due to influence of stakeholders” (x_m=3.1, s=0.7). Analysing the data, among the 18 environmental strategies, 9 have mean values $x_m \geq 3$, meaning that mean values less than 3 are also 9. The mean value of all environmental strategies (x_m=2.8, s=1.2) demonstrates that companies have moderate concerns regarding environmental responsibility.

Figure 1 shows the profile of environmental strategies by increasing order.

Figure 1 shows that mean values of environmental strategies between $1 \leq x_m < 2$ are only two, meaning a very low level of application of strategies 8 and 17. With $2 \leq x_m < 3$ there are seven strategies (15, 12, 14, 16, 13, 11, and 18), that are being implemented in a low to moderate level. On the other hand, mean values between $3 \leq x_m < 4$ are eight environmental strategies (5, 4, 3, 10, 6, 7, 9, and 2) that are implemented in a moderate to

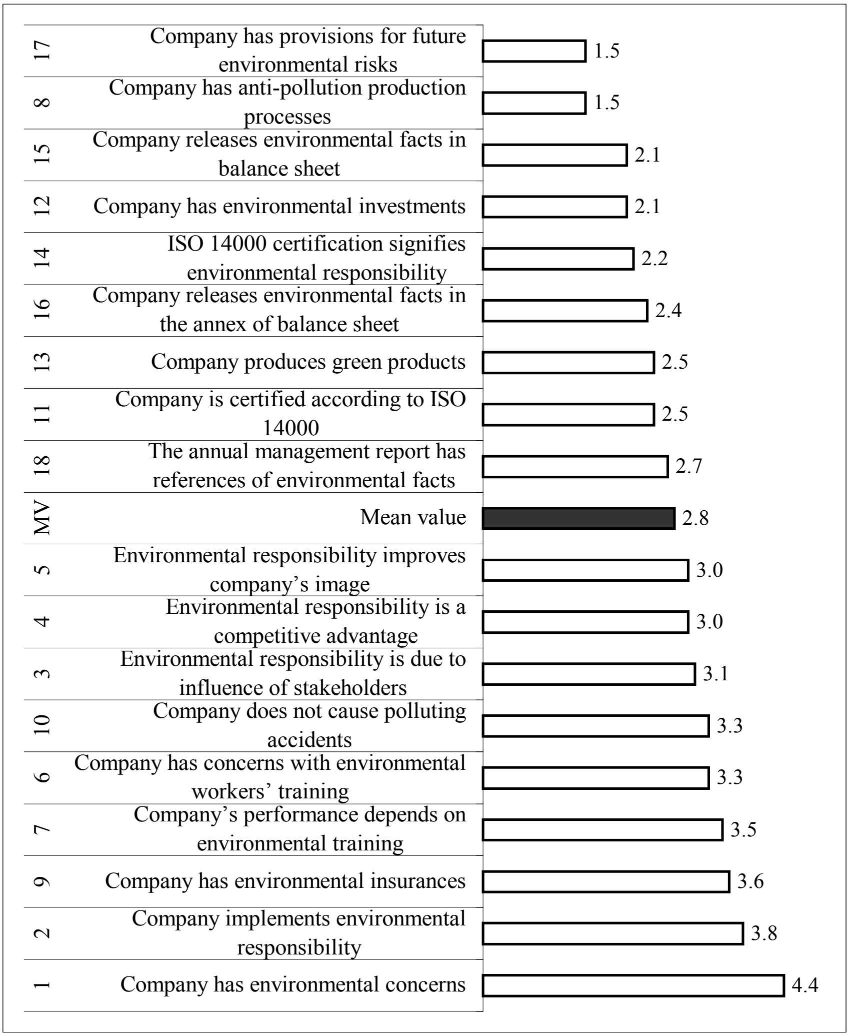

Figure 1. Profile of environmental strategies.

high level. Only one environmental strategy $4 \leq x_m < 5$ has a very high level of implementation (1).

Table 3 registers the percentage of the frequencies for each environmental strategy, considering the Likert scale from 1: never to 5: Always.

"Company has environmental concerns" is the unique strategy that has not answers in levels 1 and 2, denoting that all companies are concerned with environment, which is a public good and should be preserved, in order that future generations can have a healthy and sustainable life.

Table 3. Percentage of frequencies for each environmental strategy.

	Environmental strategies (%)	1 Never	2 Seldom	3 Sometimes	4 Often	5 Always
1	Company has environmental concerns	-	-	10.4	43.8	45.8
2	Company implements environmental responsibility	5.3	3.9	17.6	52.3	20.9
3	Environmental responsibility is due to influence of stakeholders	10.5	17.6	27.5	37.9	6.5
4	Environmental responsibility is a competitive advantage	10.4	21.6	31.4	28.8	7.8
5	Environmental responsibility improves company's image	10.4	18.3	37.3	30.1	3.9
6	Companies has concerns with environmental workers' training	17.0	11.1	18.3	30.7	22.9
7	Company's performance depends on environmental training	11.7	9.8	15.7	37.3	25.5
8	Company has anti-pollution production processes	68.6	22.9	6.5	0.7	1.3
9	Company has environmental insurances	10.5	7.8	20.3	32.0	29.4
10	Company does not cause polluting accidents	18.3	13.1	15.0	29.4	24.2
11	Company is certified according to ISO 14000	58.2	-	5.9	1.3	34.6
12	Company has environmental investments	64.8	5.2	3.9	3.9	22.2
13	Company produces green products	39.2	12.4	17.0	17.0	14.4
14	ISO 14000 certification signifies environmental responsibility	52.9	9.8	13.7	14.4	9.2
15	Company discloses environmental facts in balance sheet	50.3	12.4	18.3	10.5	8.5
16	Company discloses environmental facts in the annex of balance sheet	41.8	13.7	18.3	14.4	11.8
17	Company has provisions for future environmental risks	77.2	7.2	6.5	7.8	1.3
18	The annual management report has references of environmental facts	41.2	9.8	11.8	15.7	21.6

77.2% of companies say that they never made provisions for future environmental risks, and 68.6% of them have anti-pollution production processes what is in accordance with the fact that 64.8% of companies never made environmental investments. The strategies 8, 12, and 17 have the highest percentage levels in all inquiry.

52.3% of companies often implement environmental responsibility and 45.8% of companies have always environmental concerns. The strategies 11 "company is certified according to ISO 14000“ has one levels with zero frequency. The strategy 8 “company has anti-pollution production processes” has the lowest non-zero percentage in all inquiry and shows that only 0.7% of companies have often anti-pollution production processes. The strategy 10 “company does not cause polluting accidents” obtained answers with similar percentages in the five levels.

This set of strategies demonstrates that companies are not yet putting into practice environmental strategies, although they agree with the need to implement them.

3 Strategic Factors on Environmental Responsibility

Factor analysis attempts to identify underlying variables or factors that explain the pattern of correlations within a set of observed variables. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the observed variance in a much larger number of variables.

With factor analysis, it is possible to investigate the number of underlying factors and, in many cases, to identify the conceptual representation of each factor [7,10].

The method used for extraction of factors was the principal components analysis that should be validated through Kaiser - Meyer - Olkin (KMO) statistics and Bartlett´s test (BT) [7].

Since KMO=0.804 and considering the usual interpretation 0.80<KMO<0.90, the application of the principal components analysis is valid and the results are good [7,10].

On the other hand, for a confidence level λ=95%, the value of BT=11420.038 was high, and the associated significance level was null α=0.000, thus the factors are linear combinations of variables.

To determinate the principal components there are various rules, namely the Kaiser and the total variance explained criteria [7]. The Kaiser criterion excludes the components, with eigenvalues less than 1.

Thus, there are five principal components to retain, since the fifth and the sixth principal components have respectively eigenvalues equal to 1.019 and 0.813. These five principal components explain, according to the Kaiser criterion 74.0% of cumulative total variance explained. For a better identification of the variables that compose the factor, the rotation method Varimax with Kaiser normalization was applied [7,10].

Hence, for a confidence level λ=95%, and using the principal components method one concludes that environmental responsibility has five strategic factors (or dimensions), that contributes to measure environmental sustainability that is outlined in Figure 2, and are:

- Ethics and human resources dimension with five environmental strategies.
- Marketing dimension with four environmental strategies.
- Financial dimension with four environmental strategies.
- Quality dimension with two environmental strategies.
- Production dimension with three environmental strategies.

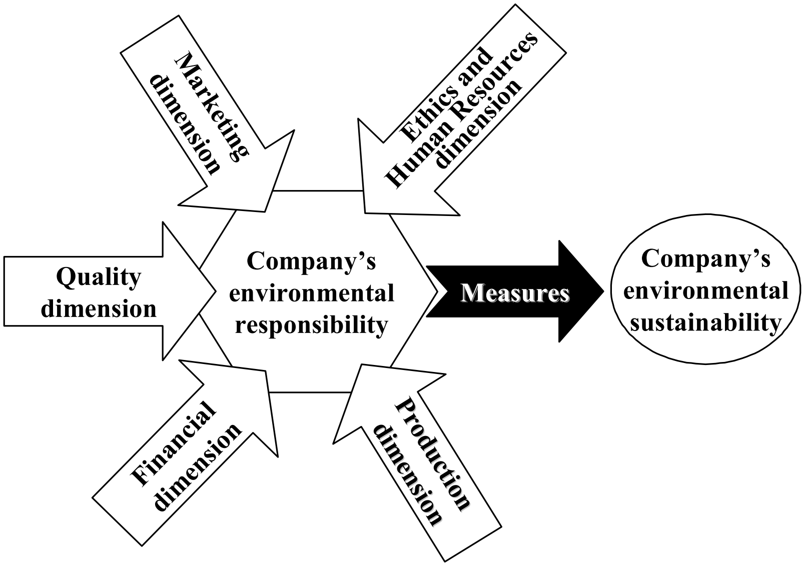

Figure 2. Five dimensions of environmental responsibility that measure environmental sustainability.

Table 4 displays the strategic factors (dimensions) of environmental responsibility. Their designation was carefully studied and nominated by the authors of the present paper. It is also registered the environmental responsibility variables, which compose the strategic factors and their loadings. These loadings mean the contribution of the variable for the strategic factors. The interpretation of the strategic factors of environmental responsibility is also author's evaluation.

The loadings of the environmental strategies that belong to a strategic factor (dimension) are different. Thus, the highest levels of loadings, for the five dimensions are as follows:

- "Environmental responsibility improves company's image" has the highest contribution (loading=0.843) in the marketing dimension.
- "Company discloses environmental facts in balance sheet" has the highest contribution (loading=0.812) in the financial dimension.
- "Company has environmental insurances" has the highest contribution (loading=0.768) in the ethics and human resources dimensions.
- "Company is certified according to ISO 14000" has the highest contribution (loading=0.744) in the quality dimension.
- "Company has anti-pollution production processes" has the highest contribution (loading=0.731) in the production dimension.

Table 4. Five strategic factors (dimensions) of environmental responsibility.

Strategic factors of environmental responsibility	Environmental responsibility variables	Loadings	Interpretation of strategic factors of environmental responsibility
Ethics and human resources dimensions	Company has environmental insurances	.768	Company has environmental insurances, does not cause polluting accidents. Its performance depends on environmental training, having globally environmental concerns.
	Company does not cause polluting accidents	.766	
	Company's performance depends on environmental training	.684	
	Companies has concerns with environmental workers' training	.662	
	Company has environmental concerns	.602	
Marketing dimension	Environmental responsibility improves company's image	.843	Company implements environmental responsibility, because it improves its image, is a competitive advantage and is due to influence of stakeholders.
	Environmental responsibility is a competitive advantage	.823	
	Environmental responsibility is due to influence of stakeholders	.620	
	Company implements environmental responsibility	.582	
Financial dimension	Company discloses environmental facts in balance sheet	.812	The annual management report has references of environmental facts and they are registered in balance sheet or in annexes. Company have provisions for future environmental risks.
	Company discloses environmental facts in the annex of balance sheet	.691	
	Company has provisions for future environmental risks	.574	
	The annual management report has references of environmental facts	.551	
Quality dimension	Company is certified according to ISO 14000	.744	Company is certified according to ISO 14000 and it signifies environ-mental responsibility.
	ISO 14000 certification signifies environmental responsibility	.703	
Production dimension	Company has anti-pollution production processes	.731	Company has environmental investments, due to anti-pollution production processes and green products.
	Company has environmental investments	.674	
	Company produces green products	.549	

However, considering all the dimensions of environmental responsibility the lowest contribution is “company produces green products” (loading=0.549) and the highest contribution is “environmental responsibility improves company's image” (loading=0.843).

4 Conclusions

Nowadays companies live in a constant change and face a global market where competition is very strong and ecological and social lobbies play an important role in business. Therefore, companies should be conscious that social and environmental responsibilities have a direct economic value.

The present research intends to measure environmental sustainability through environmental responsibility. Thus, a market study addressed to potentially polluting Portuguese companies was done. It is based on a survey that had 153 valid answers, which were processed using the statistical software package SPSS 13.0.

During the presentation of the statistical results, some conclusions were already mentioned. However the data analysis also revealed that:

- For Portuguese companies, the environmental responsibility is moderate, due to influence of stakeholders (x_m=3.1).
- Beyond the environmental concerns with very high level (x_m=4.4), companies have environmental training programs in a moderate/high level (x_m=3.5).
- The certification of environmental management systems, using ISO 14000 is low/moderate (x_m=2.5) and companies consider, in a low level, that they have an environmental responsibility (x_m=2.2).
- The number of companies that release environmental facts in the balance sheet (x_m=2.1) is low, and are almost the same that do it in the annex of the balance sheet (x_m=2.4).
- The annual management report has moderate references of environmental facts (x_m=2.7).
- Portuguese companies are moderately accepting environmental responsibility in a full perspective (x_m=2.8).

The five environmental dimensions - ethics and human resources, marketing, financial, quality and production, are the factors of environmental responsibility. In fact, a company to be sustainable should be responsible not only in internal environmental strategies but also in external, meaning a direct dependency between environmental responsibility and environmental sustainability.

Thus, a company to win the challenge of a highly competitive global market has to pursue these five dimensions of environmental responsibility that measure the company's capacity to be environmentally sustainable. The main environmental variables of the five dimensions to take into account are

- "Environmental responsibility improves company's image".
- "Company discloses environmental facts in balance sheet.
- "Company has environmental insurances".
- "Company is certified according to ISO 14000".
- "Company has anti-pollution production processes".

In spite of the first company's objective be the profit, social and environmental responsibility should be integrated in strategic planning, in order to lead company to environmental sustainability.

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SIMULATION OF SOOT FORMATION AND ANALYSIS OF THE "ADVANCED SOOT MODEL" PARAMETERS IN AN INTERNAL COMBUSTION ENGINE

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Environment issues have been in the public focus for decades, resulting in various steps to prevent or minimize dangerous combustion emissions. With the general traffic (transformation of the chemical energy into mechanical) being the main source of the emissions discussed here, main issue in this paper will consider a possible way to minimize emissions in this region. Lately, development of computer based simulations led to new mathematical models and approaches to combustion modelling. Along the usual conventional combustion models which assume certain premises to simplify the problem, new and advanced models that include complex chemical kinetics are being developed. This paper focuses on the soot formation process and the possibilities of its prediction and minimization, if possible. Based on a heavy-duty diesel engine cylinder geometry, a series of calculations were performed using a CFD software package "CFD Workflow Manager" and compared to measurements at five different load points. Variations of the mathematical soot model parameters showed certain patterns which are also described. Also, a description of the rezone meshing strategy that was used for numerical stability is given.

1 Introduction

Lately, development of computer based simulations led to new mathematical models and approaches to combustion modelling. Along the usual conventional combustion models which assume certain premises to simplify the problem, new and advanced models that include complex chemical kinetics are being developed. These are still very much limited with current computer resources, and as such enable inclusion of relatively small number of chemical reactions.

Soot, although welcome in furnace combustion processes contributing greatly to radiation heat transfer, is a dangerous product of combustion processes found in internal combustion engines.

Soot creation mechanism still isn't chemically, and especially mathematically, described, but it is known that it includes hundreds of chemical reactions and species.

Therefore, in simulations of soot creation statistical and other empirical based models are used.

Since the heavy-duty engine was used for simulations, a 3d cylinder model, representing 1/8 of a real cylinder, was made in "Imagine" module of the "CFD Workflow Manager" package. Dozens of calculations were performed varying several engine parameters as well as soot model parameters.

2 Engine Parameters and 3d Modelling

Engine used for simulations was a HD (heavy-duty) diesel engine usually found in trucks and buses. Geometrical parameters of the engine are:

- bore – 130 mm;
- stroke – 150 mm;
- swept volume 1.99 l;
- connecting rod length – 263.8 mm.

The following temperatures were used for setting the boundary conditions:

- head temperature – 500 K;
- liner temperature – 410 K;
- piston temperature – 510 K.

The calculations were performed for five different load points varying load (the amount of injected fuel), speed (in rpm), and the moment of fuel injection. The different loads were at 25%, 50% and 75%, speeds were at 1130 rpm, 1420 and 1710 rpm. The injection times were at top dead centre (TDC) or 0 °CA (crank angle degrees), and -4 °CA (four degrees before reaching TDC). Variations are denominated according to ESC (European stationary cycle) standard [1], and are:

- A_25_A_0 (low speed, low load, injection at 0 °CA);
- A_75_A_0 (low speed, high load, injection at 0 °CA);
- A_75_A_-4 (low speed, high load, injection at -4 °CA);
- B_50_A_0 (medium speed, medium load, injection at 0 °CA);
- C_25_A_0 (high speed, low load, injection at 0 °CA).

Discrete volume mesh was created representing 1/8 of the cylinder, gradually deforming from 247 °CA to 360 °CA (compression stroke) and then back to 470 °CA (expansion stroke). When this cell deformation takes place the cell layers are being squished to near zero height. Therefore, to avoid any numerical disturbances, a rezone strategy is being used to change the layer distribution along the deforming part of the mesh. Also, rezone is performed in expansion stroke to increase the number of cell to get the best results. In this case rezone action is performed at following time steps: 300 °CA, 340 °CA, 370 °CA, 380 °CA and 420 °CA. Figures 1 and 2 show the results of a rezone procedure at 300 °CA or 420 °CA (symmetrical in respect to TDC). In the case of 420 °CA Figure 2 shows the mesh before rezone.

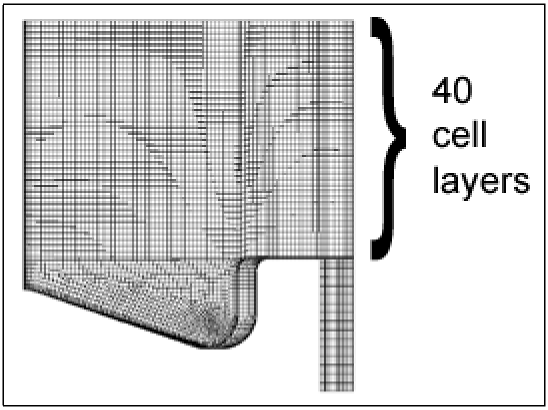

Figure 1. Mesh before rezone

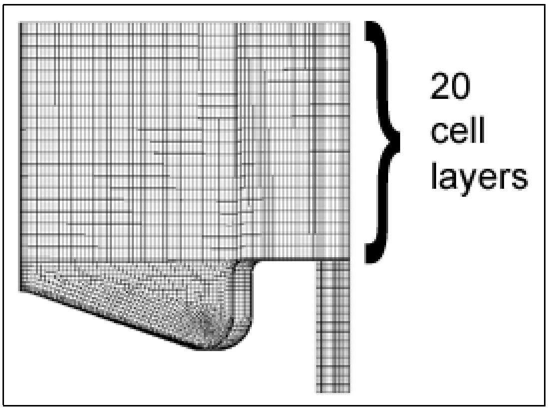

Figure 2. Mesh after rezone.

3 Theoretical Background (Mathematical Models Used In Calculations)

3.1. *Turbulent Flow*

Turbulent flow inside a cylinder was in this case simulated using k-ε turbulence model. This model is one of the most used turbulence models in industrial computations because of its proven robustness and accuracy in acceptable boundaries and is implemented in most of the CFD software. Turbulent kinetic energy is represented with a symbol k, and ε is a turbulent dissipation of the kinetic energy (Eq. 1) [2]:

$$\tilde{\varepsilon}\varepsilon\frac{\tilde{k}^2}{l_t} \tag{1}$$

Turbulent viscosity coefficient is calculated according to Eq. 2 (Cµ is an empirical constant) [2]:

$$\mu_t = \bar{\rho} C_\mu \frac{\tilde{k}^2}{\tilde{\varepsilon}} \tag{2}$$

Transport equations for k and ε are then derived from Navier-Stokes equations.

3.2. *Combustion*

Considering the extremely wide scope of the whole field of combustion theory, only the specific models that are used according to the problem will be regarded here – combustion of fuel spray and droplet combustion.

Liquid fuel combustion is usually achieved by injecting the liquid through a certain opening into the gaseous combustion chamber domain. This jet is then dispersed into the dens cloud of fuel droplets that penetrate the combustion region. Heat transfer onto each of the droplets raises the vapour pressure to the final combustion of the gas phase

Spray was simulated in "CFD Workflow manager" using mathematical models called WAVE (for dispersion), and WALLJET (for spray-wall interaction).

Type of flame that we meet while discussing combustion in an IC engine cylinder is referred to as turbulent nonpremixed flame. The main characteristic of these flames, as their name suggest, is the separate introduction of fuel and oxidizer to the combustion chamber. Since the modelling of turbulent nonpremixed flames is based on many statistical assumptions, using probability density functions and flamelet models is more than welcome. First approach defines a probability function representing a probability of a certain physical property appearing in specific intervals [3].

Flamelet model of nonpremixed flames describes turbulent flame as a laminar premixed flame imbedded in a turbulent flow field. One of basic empirical model called Eddy-breakup model was used in these simulations. This model assumes the time scale of chemistry being much smaller than the turbulent time scale and the reactants being contained in different eddies. Breakup and mixing of these eddies determines the reaction rate [4].

3.3. *Soot*

Soot is usually formed during combustion when the equivalence ratio is greater than 1. Investigation of premixed flames showed that the fuel molecules are broken down to radicals, mostly acetylene. In time, these radicals grow in two dimensions by chemical reactions, H abstraction and acetylene addition. These processes form large aromatic rings out of aliphatic species. In further stages molecules become three-dimensional and form carbonaceous particles by coagulation. The most important influences during the soot formation process come from local fuel-air ratio (C/H and C/O ratios), temperature, pressure, and residence time [4].

The "Advanced soot model" developed by Lund LTH University, calculates the volume fractions of the soot source, integrated over the mixture fraction (Eq. 3) probability density function:

$$Z = \frac{m_u + m_b}{m_{tot}} \tag{3}$$

Soot source consists out of four parts: particle inception, surface growth, fragmentation and oxidation. Different sources can be adjusted to each problem. Four scaling parameters are, therefore, introduced. For each of the soot source part there is one scaling parameter which is then multiplied with the integral surface of the different elements to qualitatively define the influence of each source on the final volume soot source [4].

4 Calculation Results

4.1. *Pressure and Temperature*

Figure 3 shows good agreement comparing calculated and measured pressure during compression and combustion. Only discrepancy is seen at the beginning of the combustion due to the fast chemistry assumed when using Eddy-breakup combustion model.

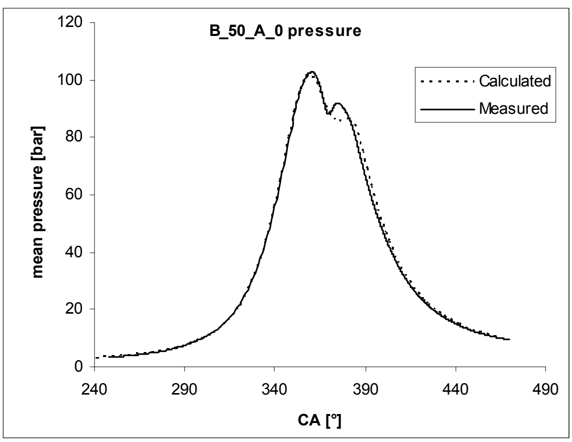

Figure 3. Mean pressure in B_50_A_0 case.

Since no experimental data was available for temperature comparison, Figure 4 shows temperature comparison for each calculated case. This chart can be used to discuss the temperature influence on soot formation.

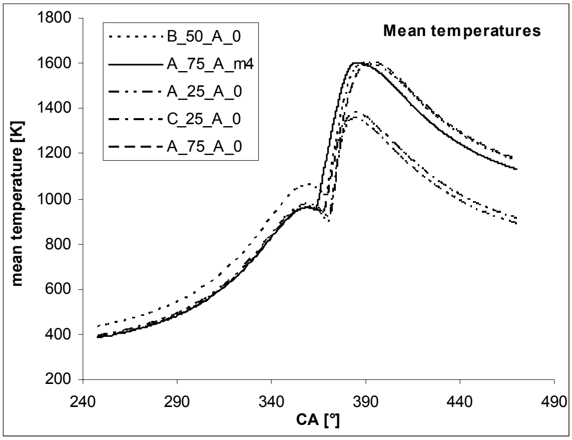

Figure 4. Mean temperature in all cases.

4.2. *Particle Inception Parameter Variations*

As seen in Figures 5 and 6, variations of this parameter produced strictly linear dependence of soot mass at the end of combustion on this parameter. This kind of dependence carries low physical value, but can be used to adjust the tendencies acquired by setting other parameters.

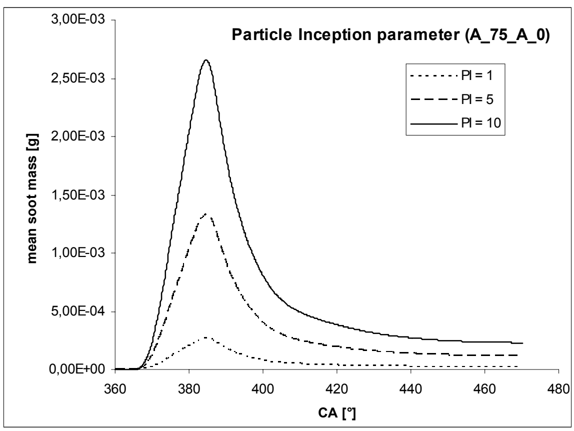

Figure 5. Particle inception parameter variations

4.3. Oxidation Parameter Variations

Since the oxidation part of the soot source has a negative sign (thus representing the sink), the increase of the resulting soot mass occurs when lowering the oxidation scaling parameter. When its value comes close to zero, which could represent the total lack of the

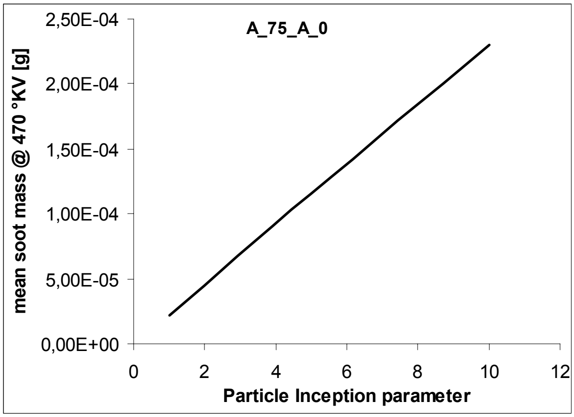

Figure 6. Soot mass dependence on particle inception parameter.

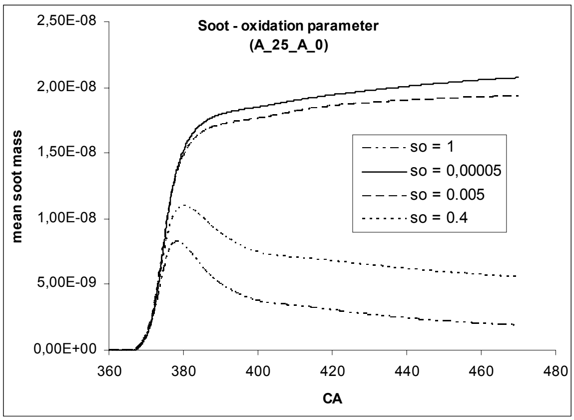

Figure 7. Oxidation parameter variations.

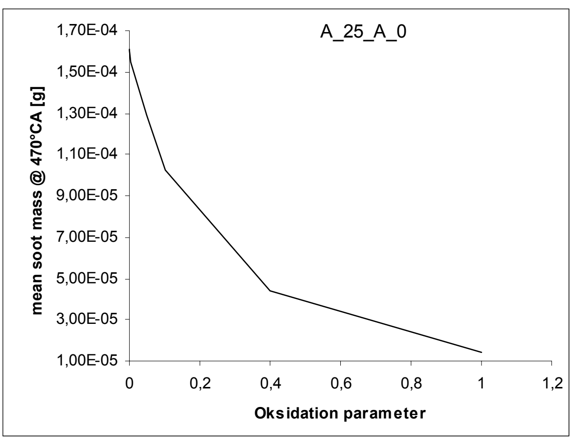

Figure 8. Soot mass dependence on oxidation parameter.

oxidation in the soot formation process, the final soot mass values are stabilized at a certain level dependant on the fuel amount (or load) and other parameters (pressure, temperature, other soot model parameter values). Increasing the parameter values over 1, the soot values would be decreased close to zero, since the oxidation is in that case a dominant process.

4.4. *Surface Growth Parameter Variations*

In Figure 10 which is showing the final soot mass dependence on the surface growth parameter, one can see that it is almost exponential. Setting the greater values of this parameter the soot concentration (or the soot mass) increases, which cannot be effectively eliminated with the oxidation in the latter part of the combustion process (this could, of course, be regulated by the adequate oxidation parameter).

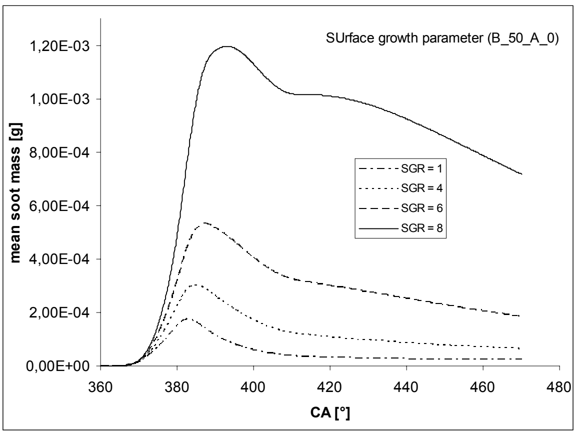

Figure 9. Surface growth parameter variations.

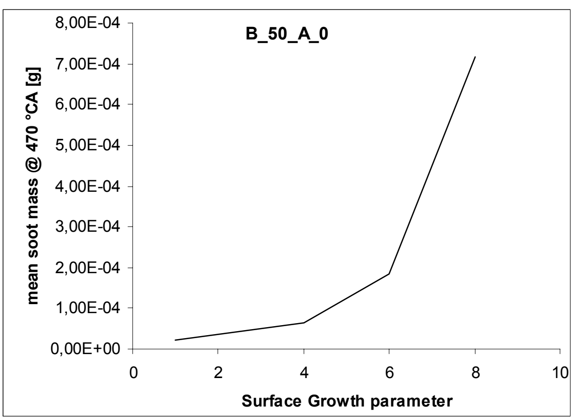

Figure 10. Soot mass dependence on surface growth parameter.

4.5. *Fragmentation Parameter Variations*

As shown in Figures 11 and 12, varying this parameter show vary small deviations from the initial ones acquired using the default parameter value (1).

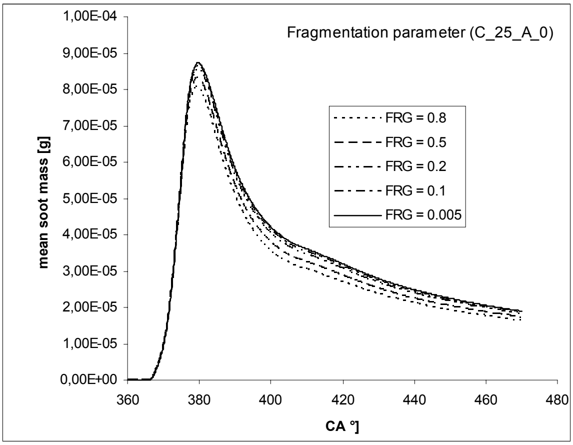

Figure 11. Fragmentation parameter variations.

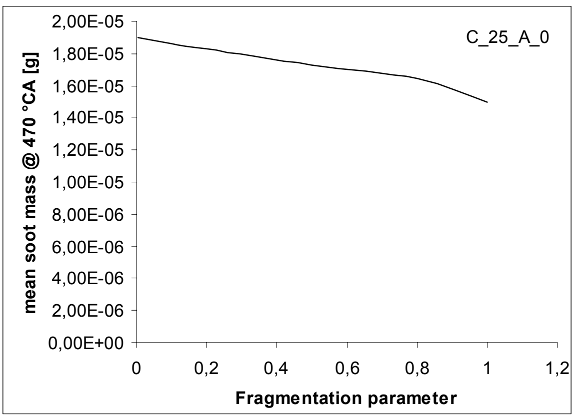

Figure 12. Soot mass dependence on fragmentation parameter.

4.6. *Optimized parameter set?*

Since the really significant results were obtained varying the oxidation and surface growth parameters, their values were set to 2 (surface growth) and 0.9 (oxidation), while leaving the other two parameters (fragmentation and particle inception) at their default values of 1. Calculation results (shown in Figure 13) show relatively good agreement (and tendencies) at the last time-step in the high-load cases (A_75_A_0, A_75_A_-4 and B_50_A_0), while the calculation results for the low-load cases are much underestimated according to the measured values. This is especially evident in the A_25_A_0 case (low load and low rotational speed), in which the calculated values are about ten times lower than the measured ones. Looking at these results, one can conclude that the final soot mass calculated by this mathematical model is heavily dependant on the amount of the injected fuel, thus giving the higher values at high-load, and lower values at low-load cases, which isn't realistic.

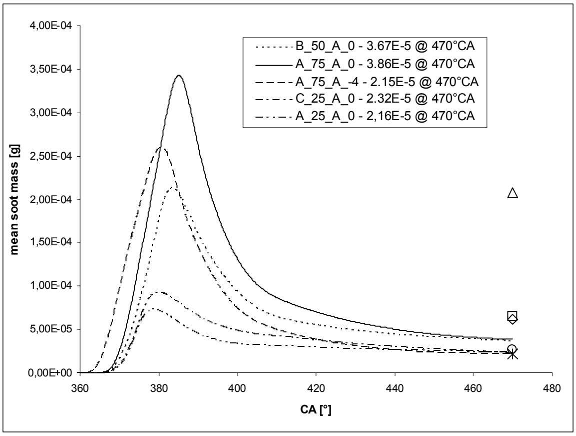

Figure 13. Mean soot mass comparison for a single parameter set on all cases.

5 Conclusion

These results have shown that using the advanced soot model, one gets the soot production mostly dependant on the mass of the injected fuel (or the load), what makes it hard to define a single set of optimized parameters for all the load cases. Also, two of the four soot model parameters have show little physical significance, one (particle inception) not giving realistic results, and the other (fragmentation) making practically no influence on the resulting values. This has shown the dominant influence of the other two parameters, oxidation and surface growth. Since only the measured values at the exhaust (last time-step) were available, it wasn't possible to assess the quality of the model during the entire soot formation process, but, as seen in the high load cases, has shown pretty good tendencies when changing the start time of the injection.

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EXERGY ANALYSE OF CHP PLANT TE-TO ZRENJANIN

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Energy savings and environmental issues, related to power generation, have prompted both researchers and industries to find high efficiency and low emission solutions. In this paper the existing CHP plant in Zrenjanin, Serbia, was analyzed. Proper modeling of the plant, by the selection of energy system's functional parameters, obtained from technical documentation and the long term measurements, was done. Mathematical model, according to the rules of energy system engineering and mass and energy balance, was the background for creating the sequential simulation software tool-*EXCHP* (software include the water/steam simulator). Techno economic consideration of possible CHP energy system improvements was carried out by the rules of exergy analyses as the part of an exergoeconomic optimization. The results confirmed the proposed mathematical model of plant and better energy performance of operating regime with combined production of power and heat, vs. separate production of heat and power. Energy performance of operating parameters is considered as the function of some important operating conditions, too. The subsystem for condensing and preheating of the condensed steam, as well as condenser, are pointed as the part and process unit with lowest exergetic efficiency.

1 Introduction

Energy savings and environmental issues, related to power generation, have prompted both researchers and industries to find high efficiency and low emission solutions. The concept of combined cycle power plants – CHP Plants, could be considered as a suitable tool for obtaining higher plant's energy efficiency than efficiency of the traditional technologies based on separate producing of heat and power. In this paper the techno economic consideration of possible improvements on CHP plant *TE TO Zrenjanin*, in Serbia is presented. The research was done by the use of the software tool for basic simulation model, *EXCHP*, developed on the *Microsoft Excel* programming platform. In order to identify the location and the magnitude of true thermodynamic inefficiencies, the performance of the plant is evaluated through exergy analysis which mathematical model is incorporated in *EXCHP*. The result of research is executed in two modes. First, design mode, analyze plant performance of existing operating conditions and regimes; the

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second, rating mode give the predictions under varying different inputs and demands. Since this is the primal investigation, analysis presented in this paper was obtained by the use of design mode. The provided information can be used as a guide for reducing the thermodynamic inefficiencies of plants and for improving their performance.

2 Brief energy system description of TE TO Zrenjanin

The reference plant, *TE TO Zrenjanin* (Figure 1), is the cogeneration plant for combined production of electrical and district heating energy and could be classified as CHP with steam cycle and extraction condensing turbine. Plant is located in the industrial zone of the city, near the existing industrial power plant *Servo Mihalj*, which is actually its substitute and supplier of steam during the start up period. The plant primary fuel is a natural gas from the near-by oil fields and the substitute fuel, in the case of accident, is heavy fuel oil.

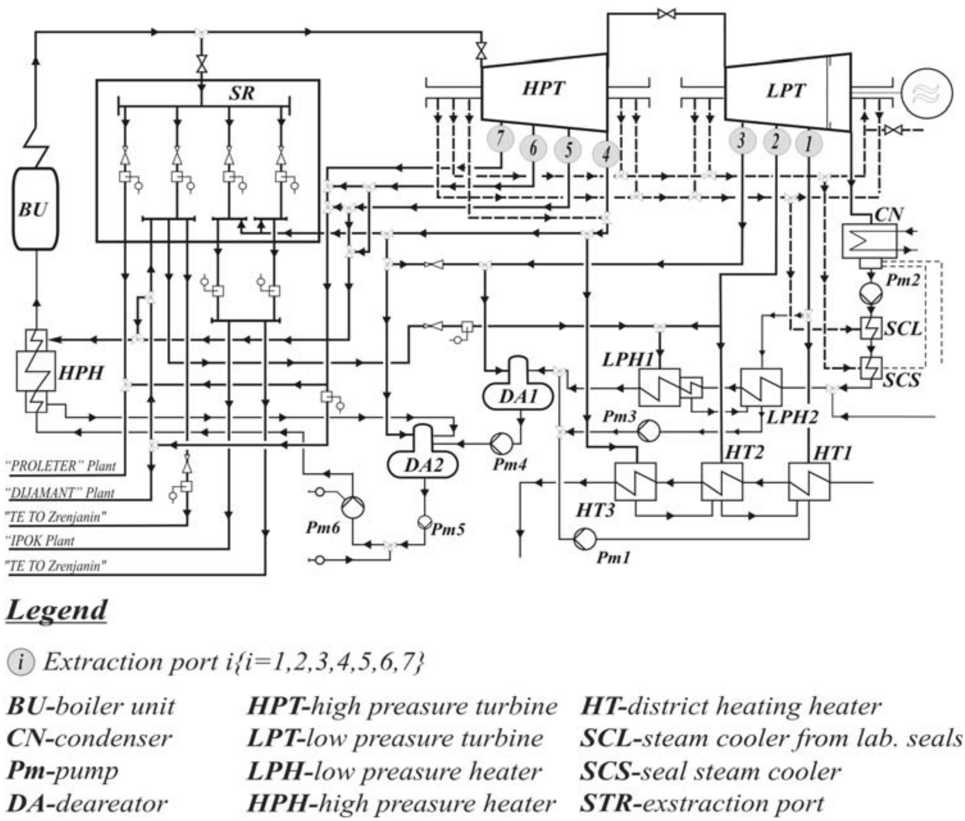

Figure 1. Technology scheme of TE-TO Zrenjanin.

The mean source for heat and energy production in the plant are two identical boiler units (*BU*), with maximum permanent steam production of 91,66 kg/s[a] per unit. The steam turbine set is equipped with seven extraction ports; the 1-3 ports (*STR 1, 2, 3*) are on the low pressure turbine (*LPT*) and the 4-7 ports (*STR4, 5, 6, 7*) are on the high pressure turbine (*HPT*). The extraction ports numbered *1* and *4* are controlled, with the possibility of regulating the pressure, while all the rest are uncontrolled.

Table 1. Steam parameters in extraction ports.

Extraction port		p_{max} (MPa)	t_{max} (°C)
1.	controlled	0,156	120
2.	uncontrolled	0,245	198
3.	uncontrolled	0,392	239
4.	controlled	0,676	295
5.	uncontrolled	2,215	321
6.	uncontrolled	3,5	378
7.	uncontrolled	6,411	462

The exhaust steam from low pressure turbine is completely condensed in the surface condenser (*CN*)[b]. Preheating of the condensed steam is done by in the low pressure preheating part of the plant which includes: the steam cooler from labyrinth seals (*SCL*), seal steam cooler (*SCS*) and two low pressure heaters (*LPH1*, *LPH2*). The mentioned devices are supplied with heating steam from the labyrinth seals and from the extraction ports numbered 1 and 2 respectively. Depending on the operation mode, the output temperature of the condensed steam from this part is in the ranges t=101°C to t=121°C.

Removing the no condensable gases from the steam cycle is realizing by the two-stage deaerators (*DA1*, *DA2*), situated on the mutual low pressure feed reservoir. In operating modes with the power output, the low pressure deaerators are supplied with steam from the third extraction port; otherwise deaerators are supplied with the steam from the steam reduction station (*SRS*). Heating up the boiler feed water from the temperature in the feed reservoir (t=175°C), to the final stage at the input of the boiler (ranges t=180°C to t=210°C), is done by high pressure regenerative heater (*HPH*).

The part of the plant for district heating utility covers all the required functions as the source for heating the city of Zrenjanin. This subsystem comprises the equipment for water heating and circulation, through pumps which overcome the resistance in district heat distribution network, The target district heating water temperature is reached by three-stage heating devices. The first two, base heaters (*HT1, HT2*), heating up the water to t=110°C, while the third, top heater (*HT3*) is used for additional heating up. The base heaters *HT1* is supplied by the steam only from extraction port numbered 1. In the case of operating mode with electrical power output the base heaters *HT2* and the top heater*HT3*

[a] Final steam parameters are p=11,77 MPa and t=540°C
[b] The steam from the vacuum expander, the steam/air mixture from the vacuum devices and additional demineralised water are also bringing into the condenser

are supplied by the steam from extraction ports numbered 2 and 4 respectively, otherwise necessary steam for these two devices is ensured by the steam pressure reduction stations.

3 EXCHP - software tool for basic simulation model

After identifying and analyzing the main components of the reference system, the creating of the appropriate physical model[c] (Figure 2) was the follow step in simulation software tool building. The model is defined as the network of inter-connected modules: turbines, heat exchangers, pumps…, as well as the new generated component of streams splitting and mixing. Model has the modular structure in order of its quickly adopting on various plant configurations.

Differently to the previous drawing (Figure 1), inside the control region, delimited by specific boundaries, the four subsystems were defined[d]:

- Subsystem of turbine aggregate; (*Turbine set*),
- Subsystem for district heating utility; (*Set 1*),
- Subsystem for condensing and preheating of the condensed steam; (*Set 2*),
- Subsystem for deariating and boiler feed water preparing; (*Set 3*).

For simulation mathematical model a flowsheeting problem formulation, as a type of steady state simulation[e], is chosen. Flowsheeting formulation (given all input information, determine all output information) was developed by applying the conservation laws for mass and energy on each component, subsystems and the whole system. Their behavior was presented by balance equations of mass and energy balance:

$$\sum_{j \in IN(i,j)} \dot{m}_j - \sum_{j \in OUT(i,j)} \dot{m}_j = 0,\ \forall i \in I\ , \tag{1}$$

$$\sum_{j \in IN(i,j)} \dot{m}_j h_j - \sum_{j \in OUT(i,j)} \dot{m}_j h_j - \dot{W}_i + \dot{Q}_i = 0,\ \forall i \in I \tag{2}$$

$$Q_i = 0,\ \forall i \in \{LPT, HPT, CN, SCL, SCS, LPH_k, HPH, HT_k, DA_k, Pm_k, M_k, SP_k\}$$

In this phase, some simplifications are included:

- Processes in all component are adiabatic,
- Streams are the ideal mixtures,
- Influence of the stream heat loses are negligible in overall heat balance,

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[c] This kind of model is typically a flowsheet of the system

[d] The subsystem of Boiler Unit is excluded due to incomplete data in available documentation

[e] This kind of energy system simulation (the simplest) was chosen because it was the first attempt for connecting the real system of plant with specialized software.

- The plant auxiliaries[f] were calculated based on the data from available tech. documentation.

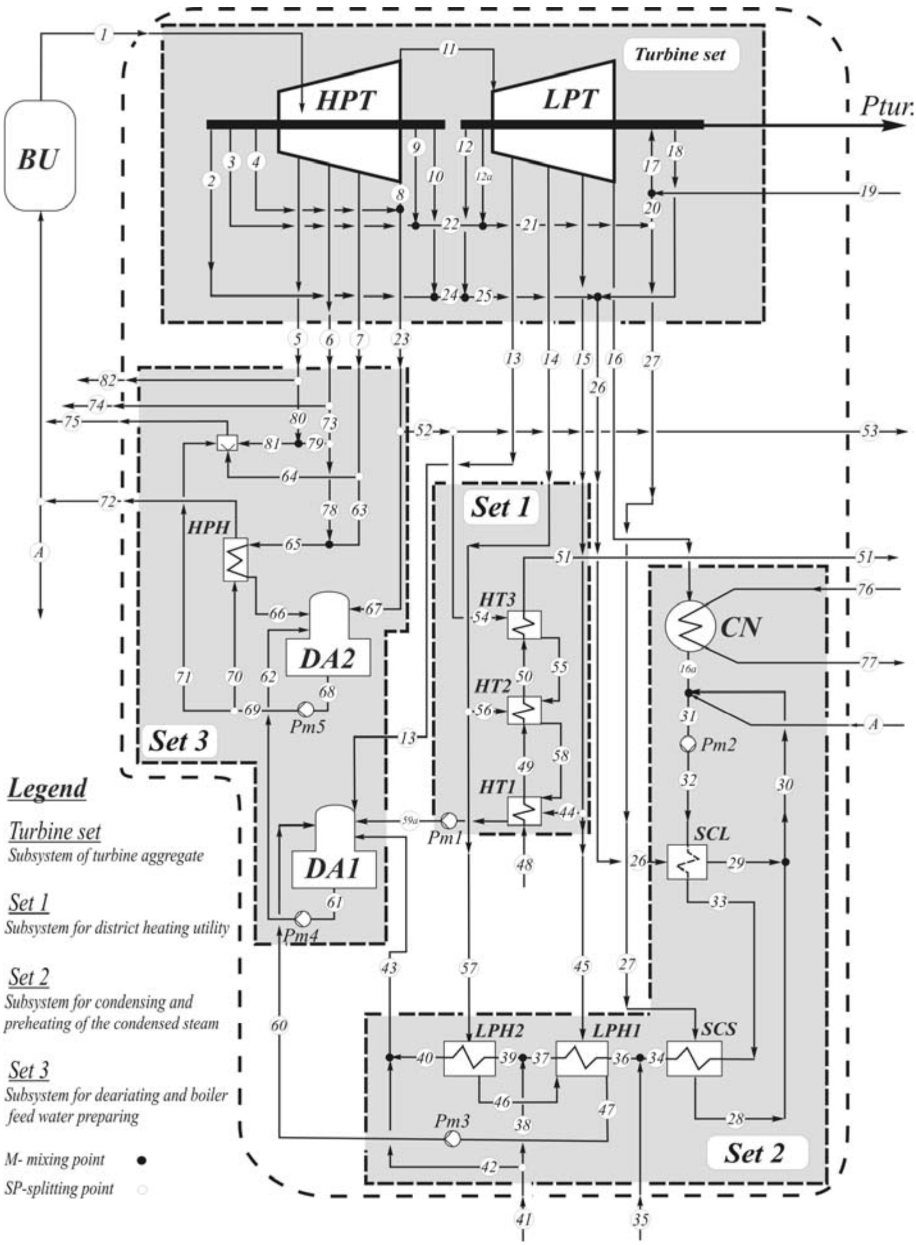

Figure 2. Physical model flowsheet of *TE-TO Zrenjanin*.

[f] These include the power consumption for the boiler feed pumps, the circulating water pumps, the steam turbine auxiliary.

Numerical integration, as the final phase of simulation, was developed on *Microsoft Excel* programming platform, by the sequential modular approach. The software is named *EXCHP*, and its flowchart is presented on Figure 3.

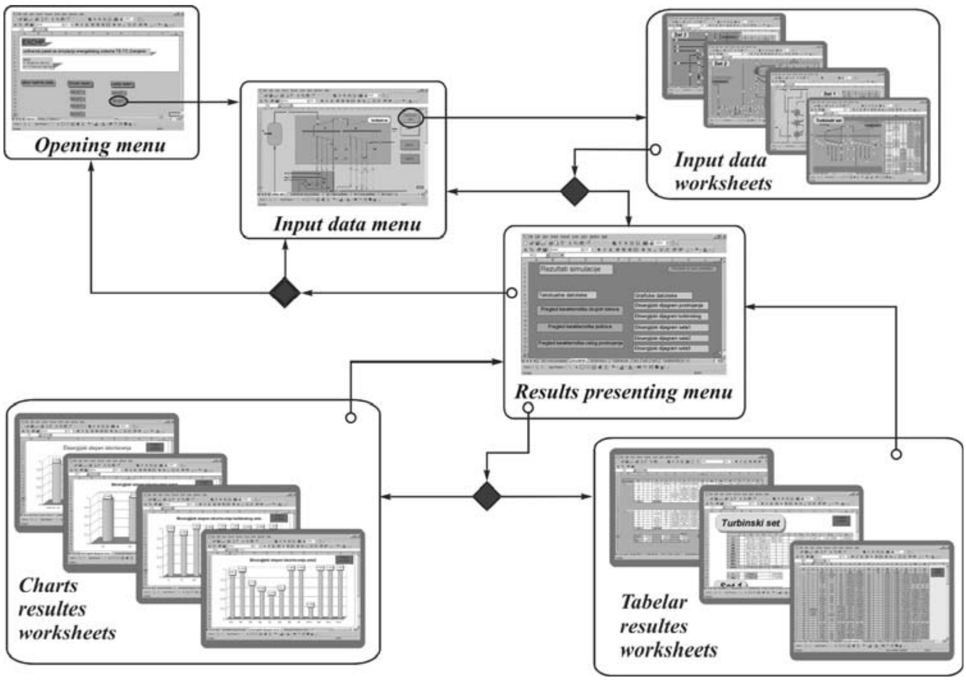

Figure 3. Flowchart of EXCHP.

Software includes the water/steam properties simulator, settled in the *Excel Add*-in component. Water/steam properties simulator is based on *IAPWS* Industrial Formulation 1997, and consists of a set of equations for different regions (Figure 4). From these fundamental equations by using the appropriate relations all thermodynamic properties of water/steam can then be calculated.

4 Exergy Analyse of Reference plant

The performance of reference plant "*TE TO Zrenjanin*" is evaluated through exergy analysis. The purpose of an exergy analysis is generally to identify the location, the source, and the magnitude of true thermodynamic inefficiencies in plants. Moreover, the results from an exergy analysis constitute a unique base for exergoeconomics.

Exergy is defined as the maximum work obtainable while the system communicates with environment reversibly. For a steady state system, the exergy balance equation could

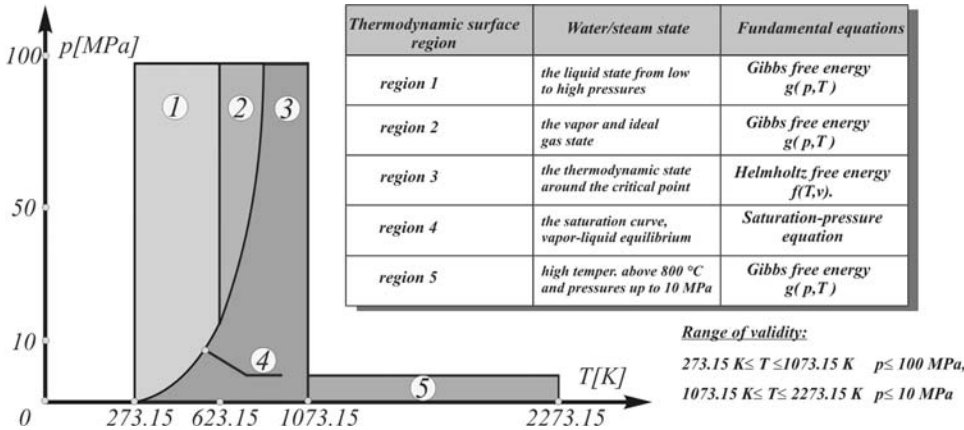

Figure 4. IAPWS regions for water/steam properties.

be presented in mathematical form as[g]:

$$\sum_{j \in IN(i,j)} \dot{m}_j e_j - \sum_{j \in OUT(i,j)} \dot{m}_j e_j - \dot{W}_i + \dot{Q}_i \left(1 - \frac{T_0}{T}\right) - \dot{E}_{L,i} = 0, \ \forall i \in I \tag{3}$$

These equations are incorporated in the mathematical model of *EXCHP*.

The key variable resulting from exergy analysis is the exergetic efficiency, which gives an unambiguous criterion for judging the performance of a plant and its components, from the thermodynamic viewpoint. For the reference plant analysis, the simple exergetic efficiency[h] is incorporated as the function in simulation software.

5 Results and discusion

The analysis presented in this paper is based on the major parameters of six operating regimes presented in Table 2. Coupling the parameters of primal steam input, power production and condenser pressure (Figure 5); the advantage of operating regimes with higher power production (steam input) and lower condenser pressure is obvious in manner of exergetic efficiency. Second conclusion is that the plant higher exergetic efficiency of regimes with combined production[i], signify its better energy performance vs. performance of separate production of heat and power.

[g] In mathematical model of presented software only physical part of exergy is counted(Appendix)

[h] The simplest form of exergetic efficiency; present the ratio of the total outgoing exergy flow to the total incoming exergy flow.

[i] From the six investigated regimes only *Winter regimes 1* and *4* are combined regimes, other are power production only.

Table 2. Major parameters of researched operating regimes.

Operating regime	Power production [MW]	Primary steam input [kg/s]	Heat transfer in DHS [MW]	Mass flow in condenser [kg/s]	Condenser pressure [bar]
Winter regime 1 (WR1)	109.8	173.611	151.04	5.5562	0.0339
Winter regime 2 (WR2)	125.5	173.611	0	45.0784	0.0857
Winter regime 3 (WR3)	53.2	59.084	0	45.8343	0.104
Winter regime 4 (WR4)	117.0	173.813	97.12	5.5561	0.0337
Summer regime 1 (SR1)	87.0	113.276	0	45.8345	0.142
Summer regime 2 (SR2)	32.4	58.695	0	18.6121	0.118

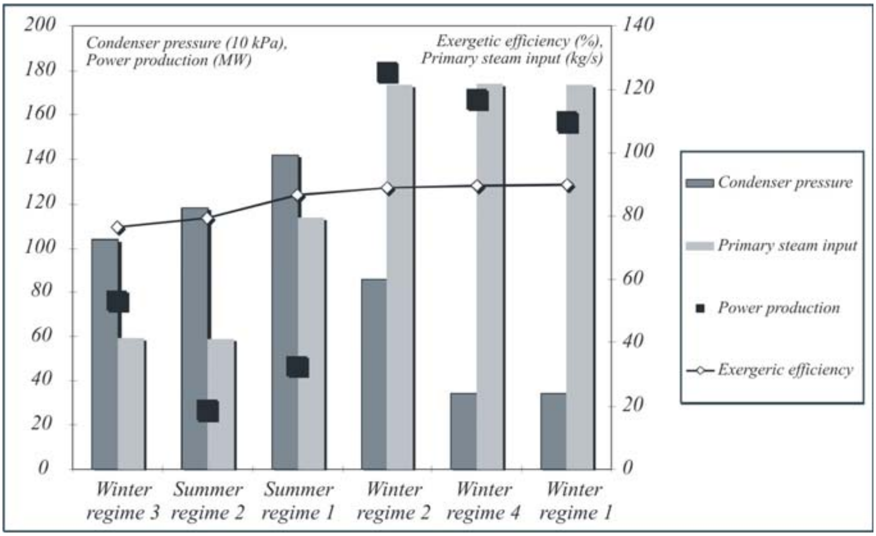

Figure 5. Plant exergetic efficiency as the function of major operating parameters.

Next step was the locating the worst exergetic efficiency indicators of the parts and the plant components. From diagram (Figure 6) it can be clearly seen, that *Set 2* (Subsystem for condensing and preheating of the condensed steam) has the lowest values of exergetic efficiency, so the following research will be applied on them.

The influence, of condenser mass flow rate and its pressure, on *Set 2* exergetic efficiency are presented on Figure 7. Obviously the minimization of mass flow rate and condenser pressure is the way for getting better energy performance of this subsystem (the whole plant too).

The origin of exergy losses was presented in Figure 8. As it could be expected the main part of losses are concentrated in condenser (except for *Winter regime 1* and *4* where the duty of *LPH1* is bigger then the duty of condenser). The influence of mass flow rate and pressure in condenser presented in Figure 9, led to the same conclusion as in the case of subsystem for condensing and preheating of the condensed steam.

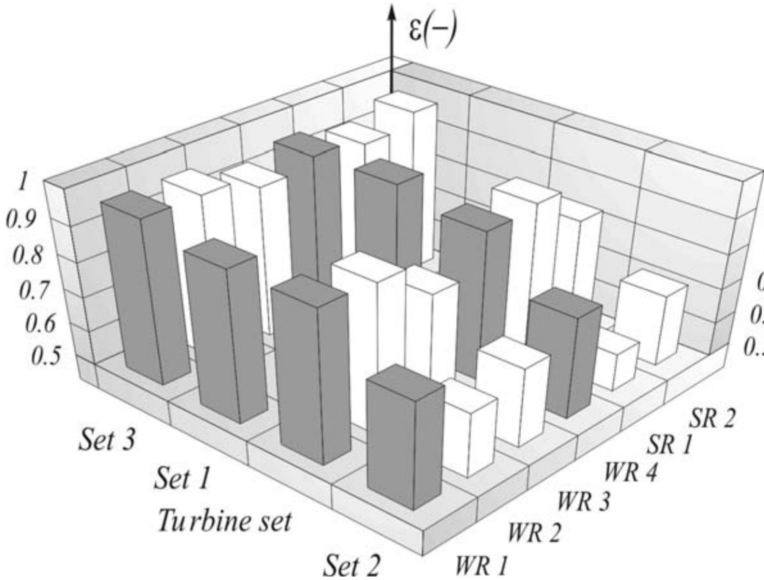

Figure 6. Subsystems exergetic efficiency as the function of major operating parameters.

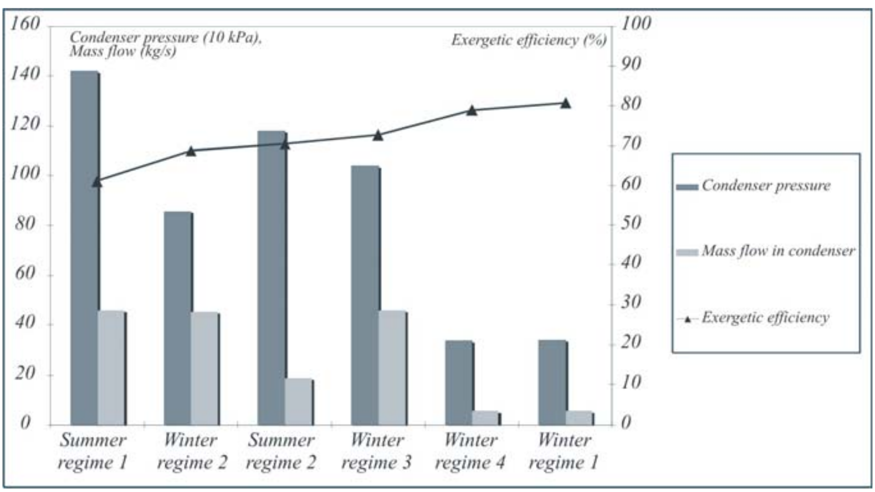

Figure 7. Exergetic efficiency of *Set 2* as the function of condenser mass flow rate and pressure.

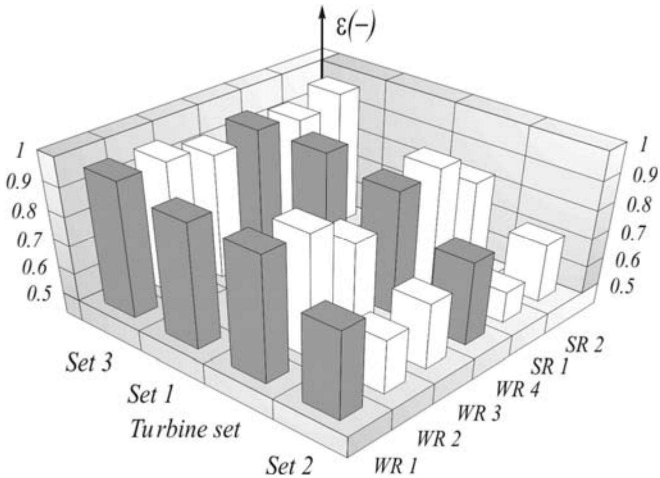

Figure 8. Exergy losses in *Set 2*.

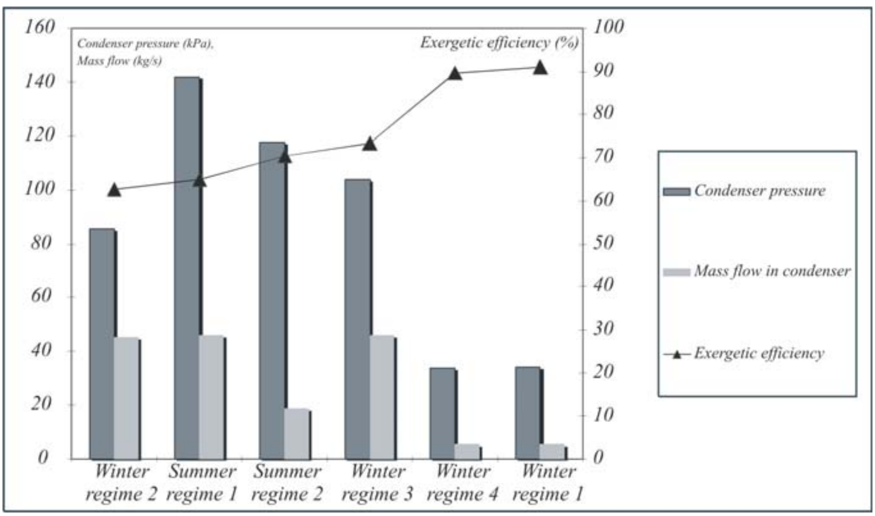

Figure 9. Condenser exergetic efficiency as the function of its mass flow rate and pressure.

6 Conclusion

Despite the widespread use of energy analysis in techno economic consideration of industrial systems, energy analysis alone can frequently give an incomplete and misleading picture of process efficiency and the opportunities for its improvements. Exergy analysis provides more rational criteria for design, evaluation, improvement, and comparison of power plants or their components from the thermodynamic point of view. The implementation of this method in software tool for basic simulation – *EXCHP*, identifies the sources and the magnitude of true thermodynamic inefficiencies in reference plant *TE TO Zrenjanin*.

This part of research was done by design mode, in order, firstly to confirm the proposed mathematical model of plant, and than to analyze the current six operating regime in plant. First analyses verify the better energy performance of operating regime with combined production of power and heat, vs. separate production of heat and power. Next, the energy performance of operating regimes is considered as the function of some important operating conditions. Last analyses signify that, subsystem for condensing and preheating of the condensed steam, as well as condenser process unit, are the parts with lowest efficiency.

The way for possible improvements could be done by choosing the optimal thermo physical stream parameters, with previously explained rate mode of software tool *EXCHP*, which will be presented in followed papers.

Nomenclature

Variables

$\dot{m}$ - mass flow rate, kg/s
h - specific enthalpy, J/kg
$\dot{W}$ - work flow (power), W
$\dot{Q}$ - heat flow, W
e - specific exergy, J/kg
$\dot{E}$ - exergy flow, W
T - temperature, K
t- temperature, °C
p- pressure, Pa

Indexes

0- environmental state
IN- inlet
OUT- outlet
L- loss
$I = \{i\}$ - process units
$J = \{j\}$ - process streams

Appendix

Flow identification and streams parameters (Winter Regime 1).

*Flow**	*Flow identification*	*x(-)*	*$\dot{m}$ (kg/s)*	*p(bar)*	*$t(^0C)$*	*h(kJ/kg)*	*e(kj/kg)*	*$\dot{E}$ (kW)*
1	Primal steam	1	173.61	108.89	535	3454.79	1569.48	272478.30
2	Steam from labyrinth seals	1	0.02	0.96	470	3425.02	943.44	21.60
3	Steam from labyrinth seals	1	0.25	1	470	3424.97	948.74	236.24
4	Steam from labyrinth seals	1	1.26	1	474	3088.04	756.55	952.49
7	Steam from extraction port	1	43.20	20.90	318.70	3064.92	1135.72	49059.47
8	Steam from extraction port	1	71.48	5.88	184.20	2816.30	863.19	61696.61
9	Steam from labyrinth seals	1	0.29	1	169.80	2815.81	635.80	184.38
10	Steam from labyrinth seals	1	0.03	0.96	169.60	2815.66	630.44	17.15
11	Steam to LPT	1	57.09	5.88	184.20	2816.30	863.19	49280.38
12	Steam from labyrinth seals	1	0.04	0.96	138.30	2753.64	609.55	21.40
12a	Steam from labyrinth seals	1	0.17	1	138.40	2753.51	614.79	103.84
13	Steam from extraction port	1	8.40	3.07	146.41	2752.80	758.56	6372.70
14	Steam from extraction port	0.98	15.01	1.60	113.30	2661.60	649.41	9748.97
15	Steam from extraction port	0.97	28	1	99.61	2613.50	578.19	16188.63
16	Steam to condenser	0.99	5.56	0.03	26.13	2513.30	132.49	736.16
17	Steam from labyrinth seals	1	0.12	1	277.15	3028.70	726.93	84.03
18	Steam from labyrinth seals	1	0.03	0.96	275.76	3026.04	720.32	24.71
20	Steam from labyrinth seals	1	0.12	1	277.15	3028.70	726.93	84.03
21	Steam from labyrinth seals	1	0.71	1	277.15	3028.70	726.93	514.59
22	Steam from labyrinth seals	1	0.54	1	311.26	3097.22	761.26	410.32
23	Steam from extraction port	1	72.73	5.70	185.81	2821	861.08	62629.54
24	Steam from labyrinth seals	1	0.05	0.96	309.71	3094.19	754.38	37.79
25	Steam from labyrinth seals	1	0.09	0.96	239.54	2953.89	686.65	58.50
26	Steam from labyrinth seals	1	0.12	0.96	249.96	2974.60	696.05	83.18
27	Steam from labyrinth seals	1	0.59	1	277.15	3028.70	726.93	430.56
28	Steam from SCS	0.06	0.59	1	99.61	553.83	82.23	48.70
29	Steam from SCL	0.04	0.12	0.96	98.47	499.73	69	8.25
30	Steam to condenser	0.06	0.71	0.96	98.47	544.75	79.74	56.76
A	Demineralised water	0	3.48	1	4.48	18.91	0.16	0.54
31	Condensate frm CN	0	9.74	0.03	26	109.02	1.70	16.56
32	Condensate from CN	0	9.74	10	26	109.94	2.62	25.52
33	Condensate from SCL	0	9.74	10	33.28	140.29	4.68	45.57
34	Condensate from SCS	0	9.74	10	26	290.73	23.75	231.41
35	Demineralised water	0	31.20	10	20	84.86	1.58	49.37
36	Water to LPH1	0	40.95	10	31.74	133.85	4.20	171.95
37	Preheating water	0	40.95	10	94.90	398.30	45.59	1866.60
38	Return water	0	33.33	10	91.50	383.99	42.33	1411.09
39	Preheating water	0	74.28	10	93.37	391.88	44.11	3276.75
40	Preheating water	0	74.28	10	107	449.31	58.01	4308.66
41	Return water	0	33.33	10	91.50	383.99	42.33	1411.09
43	Preheating water to DA1	0	74.28	10	107	449.31	58.01	4308.66
44	Steam to HT1	0.97	23.05	1	99.61	2613.50	578.19	13326.61
45	Steam to LP1	0.97	4.95	1	99.61	2613.50	578.19	2862.02
46	Water from LPH1	0	1.94	1.60	109.78	460.41	60.22	116.71
47	Water to DA1	0.01	6.89	1	99.61	435.70	53.79	370.48
48	District heating water	0	508.33	20	69.97	294.50	25.25	12835.52
49	District heating water	0	508.33	20	94.92	399.16	46.58	23680.53
50	District heating water	0	508.33	20	110.15	463.35	62.42	31727.87
51	District heating water	0	508.33	20	140.34	591.64	99.54	50597.60
52	Steam from extraction port	1	66.18	5.70	185.81	2821	861.08	56983.46
53	Steam from extraction port	1	36.76	5.70	185.81	2821	861.08	31650.59
54	Steam to HT3	1	29.42	5.70	185.81	2821	861.08	25332.87
55	Hot water to HT2	0	29.42	5.70	143.50	604.35	102.53	3016.33
56	Steam from extraction port	0.98	13.07	1.60	113.30	2661.60	649.41	8490.41
57	Steam from extraction port	0.98	1.94	1.60	113.30	2661.60	649.41	1258.56
58	Hot water to HT1	0	42.49	1.60	111.90	469.42	62.59	2659.60
59	Hot water to DA1	0	65.54	1	98.25	411.72	48.02	3147.32
59a	Hot water to DA1	0	65.54	6	98.25	412.10	48.40	3172.06
60	Hot water to DA1	0	6.89	5	99.61	436.10	54.19	373.23
61	DA1 exit water	0	155.11	3.07	132.67	557.76	87.81	13619.56
62	DA1 exit water	0	155.11	20	132.67	558.96	89.01	13806.15
63	Steam to HPH	1	17.29	20.90	318.70	3064.92	1135.72	19630.83
64	Steam from extraction port	1	25.91	20.90	318.70	3064.92	1135.72	29428.64
66	Steam from HPH	0	17.29	20.90	156.60	638.95	114.96	1987.01
67	Steam from extraction port	1	6.56	5.70	185.81	2821	861.08	5646.08
68	DA2 exit water	0	178.95	5.70	154	649.57	117.41	21011.51
69	DA2 exit water	0	178.95	150	156.40	668.69	134.31	24034.47
70	DA2 exit water	0	177.08	150	156.40	668.69	134.31	23783.32
71	DA2 exit water	0	1.87	150	156.40	668.69	134.31	251.15
72	Boiler feed water	0	177.08	150	210.66	905.49	224.25	39711.10
75	Steam from expander	1	27.78	20	250.16	2903.63	1051.06	29200.61
76	Water to condenser	0	1600	5	20	84.39	1.08	1731.98
77	Water from condenser	0	1600	5	22.02	92.74	1.40	2238.08

*The stream which doesn't exist in WR1, in the Fig. 3., are exclude from the table.

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DEVELOPMENT OF ENVIRONMENTAL GUIDELINES FOR THE REGION OF WESTERN BALKANS

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It is well known that a severe environmental damage in the area of the Western Balkan Countries was caused by the recent war. Moreover, in some countries the transition process to the market economy amplified these effects. Furthermore, serious environmental concerns were raised about the release of toxic chemical factories and oil refineries, potential impacts to biodiversity, the damage of the natural habitat and the historical heritage, the destruction of existing wastewater plants and the contamination of air, soil, vegetation and water. At the moment, Western Balkan countries find themselves in a difficult economic situation and the environment is not considered to be a high priority. WEB ENV is a project aiming to address issues related to the ***making good of the consequences of the war*** in the environment through the extraction of conclusions for a number of common environmental problems related to Western Balkan countries in specific matters. Furthermore, the Project will examine these problems and will evaluate them while it will recommend the appropriate solutions. It will also ***support*** in particular the ***Community's external relations*** and ***development aid policies*** such as EU Water Initiative, the Commitment towards the Millennium Development Goals and the Action Plan for R&D Cooperation between EU and the Balkan Countries. More specifically, the main objective of WEB-ENV project is the development of general environmental guidelines concerning the region of Western Balkan Countries, with a particular focus on water resources, renewable energy and use of recycled materials. These guidelines could be useful for the formation of a generalized approach for the management of major environmental problems and natural resources as well. This will be reached by the following:

- Extended mapping exercise to identify these problems
- Development of evaluation criteria permitting the selection of the most significant problems in terms of water resources planning and policy, wastewater treatment and reuse technologies, use of recycled material, renewable energy and hybrid systems, taking into account the socio-economic and human health impacts
- Assessment of innovative low-cost remediation technologies
- Review of the existing legislation of each country in comparison with the EU Environmental legislation and EU environmental directives.

The development of general environmental guidelines is expected to contribute to the formation of a common environmental policy and sustainable management of natural resources in the region, to arise peoples' sensitivity in crucial environmental problems, to contribute to the economic development of the region and to provide assistance to all the stakeholders involved with the enhancement of the political and social situation in Western Balkans.

1 WEB-ENV Project Content

WEB –ENV Project's realization will lead to the development of general environmental guidelines concerning all the region of Western Balkan Countries that could be usesful for the formation of a generalised approach for the management of environmental problems of great significance of the region and natural resources. To achieve this:

An extended ***mapping exercise*** will be carried out in each country, for the identification and evaluation of important environmental problems of the Western Balkan region, with particular focus in problems related to water resources planning and policy, wastewater treatment and reuse technologies, use of recycled material, renewable energy and hybrid systems. The duration of the mapping exercise is estimated to one year.

A reliable ***environmental map*** of the region will be developed, depicting the areas with significant environmental problems and recording the rehabilitation needs for each case will be based on the mapping exercise. In this map, it will be implemented a selection of the most important cases of these problems taking into account subjects such as the impact on human health and social and economic impact and it will be included extensive summaries with the already existed proposed solutions, other extensive relative reports and also technoeconomical data for each case.

A limited number of environmental problems will be defined and will be studied as "***case studies***".

Low cost innovative technologies will be identified and assessed, in order to be implied for the remediation of the identified environmental problems.

The ***existing legislation on the Western Balkan Countries' environmental issues*** will be reviewed and disseminated

4 techno economical ***preliminary feasibility studies*** of cases of great significance (one for each participating country from the Western Balkan region) will be carried out. ***Environmental guidelines will be prepared***, taking into account socio- and techno-economic parametres for each country and for the region of Western Balkans as well, encouraging the transnational research, technological and scientific colaboration.

A web-portal will be developed as an effective support tool to be utilised within the project and will provide reliable and up-to-date information on issues such as:

- Water resources planning and policy.
- Wastewater treatment and reuse technologies.
- Flood / drought prevention and control.
- Use of recycled material.
- Renewable energy and hybrid systems.
- Legislation of the Western Balkan Countries related to aforementioned issues.
- Directories of open programmes and funding mechanisms.
- Innovative low-cost technologies for substantial energy savings.

In addition, WEB-ENV portal will provide information about ***open programmes and funding mechanisms*** and hopefully it will be a useful awareness mean providing information on opportunities offered by international organizations (e.g. European Union, United Nations, UNESCO, International Bank, European Investment Bank, European Agency for Reconstruction etc.), the financing of projects designed for the solution of environmental problems of the region:

- Encouragement of the cooperation between scientific, research and industry world with expected multiplying effects that will satisfy existing information needs of both scientists and business people and will enhance a regional sustainable socio-economic development.
- Effective public awareness, arising people's sensitivity in crucial environmental problems and sustainable socio-economic development of the region.
- Encouragement of the transboundary collaboration between the countries of the region.
- Worldwide publicity of the research activity carried out in the Western Balkan Countries to the rest of the world.
- Help researchers and research organizations to have easy access to knowledge and expertise not available until now.
- Stabilization and reinforcement Research Potential of the Western Balkan Countries.
- Help in the solution of global environmental problems e.g. the global water crisis and work towards the objectives of the EU Water Initiative and Millennium Development Goals.

The potential impact of WEB-ENV Project is expected to contribute significantly to efforts carrying out in the region now or in the near future aiming to offer ***solutions in major environmental problems***, and therefore to the ***economic development*** of the Western Balkan Countries. The assistance that will be provided could be helpful to all the stakeholders involved with the ***enhancement of the political and social situation*** in the Western Balkan region.

It should also be mentioned that WEB-ENV will work towards European Union's environmental policy by developing general guidelines for major environmental problems for the Western Balkan region.

Additionally, the project will encourage the collaboration between scientific groups, research organizations and industry partners from the Western Balkan Countries and will strengthen local and national capacities on environmental management.

2 Strategic Impact and Contribution to Others EU's Policies

Additionally, to the above mentioned, WEB-ENV Project is in full accordance to certain EU' s Policies such as:

- EU Water Initiative, which aims to achieve a secure water future for all. The water global crisis is a threat to the environment, to economic development, to poverty reduction, to peace and security. Solving water problems means environmental, economic and social progress. WEB-ENV project is going to work towards this objective and provide information about integrated management of regional water resources. This can be assured by the participation in the project of partners with significant experience, infrastructure, and equipment in relative issues and especially the *Hydro-engineering Institute in Sarajevo, which specializes* in water management, hydro-engineering and environmental engineering.
- The Millennium Development Goals, which are accepted by the international community including the European Commission. Specifically, there will be

contribution to the as*surance of environmental sustainability,* which is one of the Millennium Development Goals, by proposing suitable solutions for major environmental problems of the region.
- Other European's Union's policies, by supporting the external relations and encouraging trans regional partnerships and international cooperation, as the project involves collaboration between organizations of the Western Balkan Countries.
- Action Plan for S&T Cooperation between EU and the Balkan Countries, adopted during the EU-Balkan Countries Ministerial Conference held in Thessaloniki, on June 27, 2003, promoting the general goal of this Action Plan, in the Western Balkan Region. Namely:

1. Creation of atmosphere of understanding of EU RTD policies and strategies.
2. Creation of general conditions for integration into EU RTD activities.
3. Creation of potentials and capabilities for full participation in ERA, FP6 and other European programmes, in the future.
4. Particularly, concerning the goal of the Cooperation related to Environment (monitoring, improvement, water management), the project will develop a clear regional concept on decentralized water management based on innovative technologies.

3 Exploitation and Dissemination Plan

Results can be exploited by all the stakeholders involved with the development of a common environmental policy and administration of natural resources and specifically:

- Optimum energy management
- Optimum water resources exploitation.
- Effective wastewater treatment and reuse technologies.
- Application of innovative, clean and low-cost technologies.
- Effective prevention and control flood / drought.
- Better use of recycled materials.
- Arising people's sensitivity in crucial environmental problems
- Improvement of the environment, the quality of life and long-term prosperity.

The environmental map and the portal in general of the Western Balkan Countries' can provide a better image of the region, and can be useful tools to stimulate international funding organizations as the European Union, the United Nations, UNESCO, the International Bank, the European Investment Bank, etc., to grant new projects in the region.

WEB-ENV project's results can be exploited as well for the transregional co-operation between the countries of the Western Balkan Countries, in common environmental problems and in addition for the co-operation between the aforementioned countries and the European Union.

To facilitate the results dissemination, the design of an effective dissemination / awareness campaign is necessary. The main objective of this *dissemination plan* will be to increase the awareness of special target groups such as governmental organizations, research institutions, universities, research centres, environmental organizations, industry, general public etc. In order to attain this target, the following activities will be carried out:

1. Mapping exercise of the existing environmental problems.
2. Evaluation of these problems by the Groups of experts and adoption by the Steering Committee of a limited number of cases of major importance
3. Presentation of the results from the mapping exercise and the evaluation process in the workshops
4. Distribution of questionnaires related to these presentations during the workshops. Additionally, these questionnaires will be mailed to the main stakeholders (Government, Local Authorities, Academia, Private sector/Industry). The study of the feedback from the questionnaires will be the basis related to develop the environmental guidelines for WBC.

4 Conclusion

In conclusion, the most important impact of the WEB-ENV project, will be the contribution to the development of an environmental policy with consequences the improvement of the environment, the quality of life and the sustainable development of the Western Balkan region by the recommendation of solutions for the prevention or remediation of most important environmental problems.

HIGH EFFICIENCY HEAT AND MATERIAL RECOVERY OF PLASTIC WASTE INCLUDING POLYVINYL CHLORIDE BY USING SUMITOMO METALS' WASTE GASIFICATION AND SMELTING SYSTEM

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Ordinary waste treatment systems have problems caused by low heat and material recovery, such as the emission of dioxin and heavy metals. To promote heat and material recovery, a new type of waste gasification and smelting system, using iron-making and steel-making technologies based on high-temperature metallurgy, has been developed for much kind of wastes. This system can steadily gasify and smelt municipal waste and industrial waste such as plastic waste including polyvinyl chloride, automobile shredder residue, soil and so on. As a result of steady operation in the high temperature reduction atmosphere, dioxin-free high calorie purified gas and heavy metal-free high quality slag were produced. Three commercial plants which have capacities of 132tons/day (2 units of 66tons/day) based on municipal waste in Tosu, Japan and 100tons /day (1 units of 100tons/day) based on industrial waste in Yamaguchi and Kashima, Japan have been operating at full capacity.

1 Introduction

In Japan, waste incineration and landfilling of bottom ash have been adopted for waste treatment, but ordinary waste treatment systems have problems caused by low heat and material recovery, such as the emission of dioxin and heavy metals. As might be suspected, this is a global concern as well as a Japanese one. In Europe, thermal treatment of waste is one of the options prescribed by the European Commission in its waste management protocol: prevention, material recycle, energy recovery and landfill [1]. A major change has been considered necessary since the European waste directive called for a 30% reduction of the amount of waste sent to landfill by 2010. To promote heat and material recovery, a new type of gasification and smelting system, using iron-making and steel-making technologies based on high-temperature metallurgy, has been developed for municipal waste [2]. This system, Sumitomo Metals' waste gasification and smelting system can produce dioxin-free high calorie purified gas, which can be used for high efficiency power generating system using a gas engine or turbine. And ash components in the municipal waste are smelted in a high temperature reduction atmosphere and the heavy metal-free high quality slag is produced. Furthermore, this system will be applied for high heat and material recovery of not only for municipal waste and also industrial waste such as plastic waste including polyvinyl chloride (herein after as "PVC"), automobile shredder residue and other treatment-resistant waste [3], because the temperature in the furnace can easily be controlled by using top and sideways blow oxygen lances. There will be high heat and mass recovery, production of dioxin-free high calorie gas and heavy metal-free high quality slag, and recovery of chlorine. In this paper, gasification and smelting test results using municipal and industrial wastes were described.

2 Basic Concepts

Figure 1 shows the basic concepts of Sumitomo Metals' waste gasification and smelting system.

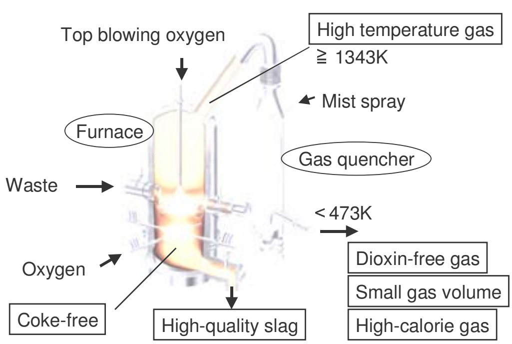

Figure 1. Basic concepts of the Sumitomo Metals' gasification and smelting system.

The furnace is a shaft type in which waste is gasified and smelted in one process. Waste-packed bed is formed in the lower half section of the furnace. The sideways blow oxygen lances are provided in the packed bed area and a top blow lance is placed at the top of the furnace. The basic concepts of this system are steady operation by using top and sideways blow oxygen lances, production of dioxin-free high calorie purified gas and production of high quality slag. These concepts were clarified by a 2ton/day-bench furnace test using dried municipal waste. The explanations of the concepts are as follows.

2.1. *Steady Operation by Using the Top Blow Lance*

Figure 2 and Figure 3 show effects of top blowing oxygen. By using top blow lance together with the sideways oxygen lances, the top gas composition was stabilized because uniform gas flow will be produced in the top part of the furnace. And coarse dust flying (particle size is over 0.1mm) was prevented by using top blowing oxygen. Figure 4 shows inside wall of the furnace after the gasification and smelting test. Melting dust was

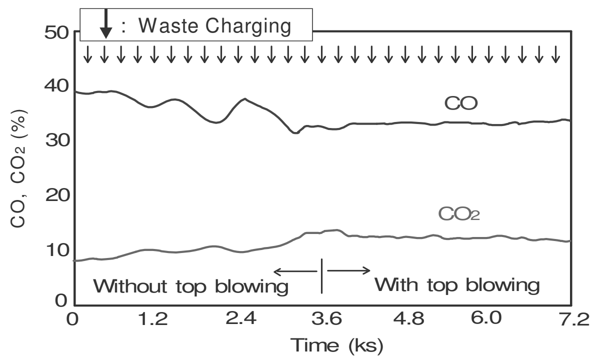

Figure 2. Effect of top blowing on stability of top gas composition.

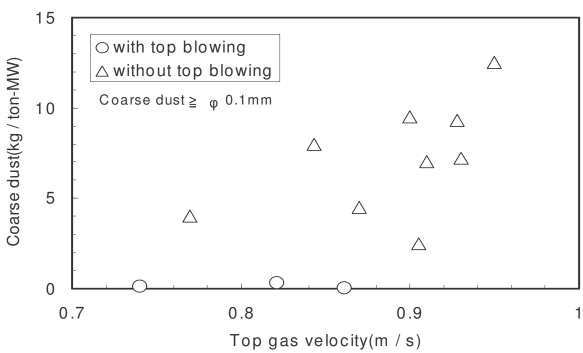

Figure 3. Effect of top blowing oxygen on coarse dust dispersion.

With top blowing   Without top blowing

Figure 4. Formation of dust-coating layer on the inside wall of the furnace.

uniformly coated on the inner wall of the furnace with top blowing oxygen as shown in Figure 4. Namely dust was trapped on the inside wall and coarse dust dispersion was prevented. Formation of the dust-coating layer on the inside wall of the furnace will not only prevent dust flying but also protect the inside wall. The coated dust will go down the inside wall and become slag. Furthermore, molten slag is steadily produced by top blowing oxygen because the high temperature zone is concentrated toward the centre of the furnace. As a result of using the top blow lance, this system can be steadily operated over long term.

2.2. *Production of dioxin-free gas*

For reduction of dioxin emission, waste is gasified in high temperature reduction atmosphere of over 1343K and the off gas is rapidly quenched to about 443K by a mist spray type quencher. In the gasification and smelting test using municipal waste, the concentration of dioxins after gas treatment was less than 0.01ng-TEQ/Nm^3.

2.3. *Reduction of off gas volume and production of high calorie gas*

The off gas volume will be theoretically reduced to about 25% by combining oxygen blowing and waste drying in comparison with a conventional process, which used municipal waste that was not dried and air blowing for combustion. Furthermore, waste drying and oxygen blowing produced high-calorie gas, which contained a large quantity of CO and H_2. The high calorie gas will be used for high efficiency power generating system using a gas engine or turbine.

2.4. *Production of high quality slag*

Ash components in the waste are smelted in the high-temperature reduction atmosphere to produce heavy metal–free high quality slag. Heavy metals easily become volatile and concentrated in the generated gas or dust. As the absolute quantity of heavy metals contained in the slag is very little, the produced slag can be used for roadbed material.

3 Basic Flow

Basic flow of Sumitomo Metals' gasification and smelting system was constructed based on the above-mentioned basic concepts. Figure 5 shows the basic flow of this system. Municipal waste is charged into the furnace after shredding and drying. A shaft-type furnace is equipped with a top and sideways blow lance to supply oxygen into the furnace for waste gasification and smelting. The exhaust gas from the furnace was maintained at 1343K or more, and it is rapidly quenched though the gas quencher for reduction of dioxin emission. After gas quenching, dust and chlorine in the exhaust gas is removed at bag-filter, and hydrogen sulfide is removed at a wet desulfurization reactor. The chlorine in the exhaust gas is removed by slaked lime injection into bag-filter. And the purified exhausted gas is used for high efficiency power generating system using a gas engine or turbine. In the gasification and smelting of plastic waste including PVC, exhausted gas temperature after gas quenching is maintained at over 413K for prevention of the corrosion from hydrogen chloride produce from PVC. And collecting system of hydrogen chloride will be installed after gas quenching or bag-filtering process in a commercial plant.

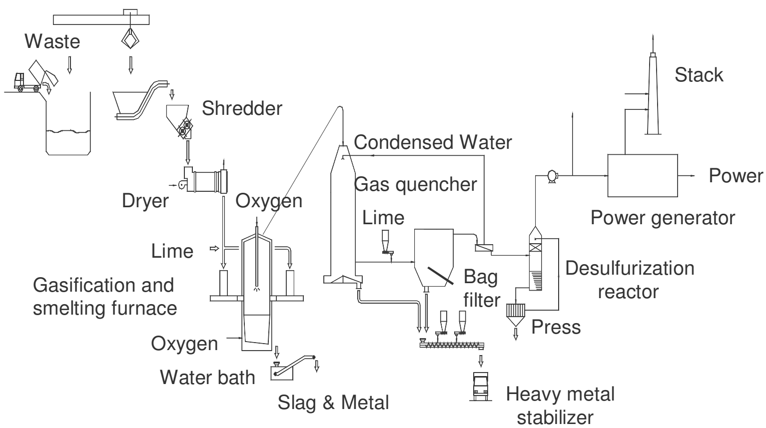

Figure 5. Basic flows of Sumitomo Metals' gasification and smelting system.

4 Gasification and Smelting Test Results

4.1. *Materials and Methods*

The gasification and smelting test using municipal and industrial wastes was conducted by using a 2ton/day-bench furnace system. Table 1 shows the technical analysis value of waste samples. Refuse Paper and Plastic Fuel (hereinafter refer to "RPF"), actual plastic waste, PVC, housing waste, automobile shredder residue (hereinafter refer to "ASR") and simulated plastics, which are mixtures of RPF and PVC were used. Concentrations of volatile matters in the RPF, plastic waste, PVC and housing waste are much larger than that in dried municipal waste and ASR. And concentration of ash in ASR is much larger than that in other sample wastes. Table 2 shows the chemical compositions of the waste samples. Chlorine content in PVC and housing waste are greater in comparison with other wastes. In this test, mixing ratio of RPF and PVC is changed to clarify influence of chlorine content for dioxin emission.

Table 1. Technical analysis values of waste samples.

	Dried Municipal Waste	R P F	Plastic Waste	P V C	Housing Waste	A S R
Volatile Matter (wt %)	62.2	90.5	92.3	84.4	88.6	51.8
Fixed Carbon (wt %)	19.0	1.1	2.6	11.9	10.2	5.9
Ash (wt %)	9.8	7.5	4.6	3.5	1.02	33.9
Moisture (wt %)	9.0	0.9	0.5	0.2	0.2	8.4
Bulk Density (ton/m^3)	0.1	0.35	0.30	0.59	0.45	0.4
Low Calorific Value (kJ/kg)	15873	36879	35418	19172	19574	18799

Table 2. Chemical compositions of waste samples.

		Dried Municipal Waste	R P F	Plastic Waste	P V C	Housing Waste	A S R
Combustible (wt %)	C	40.0	71.2	76.0	37.6	38.5	39.5
	H	6.3	10.9	9.0	4.7	4.8	4.7
	O	32.2	7.8	6.4	6.2	22.4	9.5
	N	0.9	1.0	0.36	0.0	0.03	1.1
	S	0.12	0.11	0.03	0.08	0.04	0.30
	T-Cl	1.7	0.53	3.15	47.75	33.06	2.5
Ash (wt%)		9.8	7.5	4.6	3.5	1.02	33.9
Moisture (wt%)		9.0	0.9	0.5	0.2	0.2	8.4
Heavy Metals (ppm)	Cd	1	< 1	2	5	20	6
	Cr	< 10	< 10	< 10	< 10	< 10	167
	Hg	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01
	Pb	39	50	10	< 10	19200	3380
	As	< 1	< 1	< 1	4	93	5
	Se	< 50	< 50	< 50	< 50	< 50	< 50

4.2. *Operation Stability*

Table 3 shows overall results of the furnace operation. The 2 ton/day-bench furnace system can steadily gasify and smelt RPF, 100% PVC, 100% actual plastic waste, mixture of RPF and PVC, housing waste and ASR the same as dried municipal waste. The main components of the product gas are CO and hydrogen. Top gas temperature was maintained at over 1373K and residence time of the product gas in the furnace is more than 2 seconds. The high temperature gas was rapidly quenched to 443K at mist spray type gas quencher for reduction of dioxin emission.

Table 3. Overall results of 2ton-MW/day-bench furnace operation.

			1	2	3	4	5	6	7
Sample (kg/hr)	Dried Municipal Waste		70	0	0	0	0	0	0
	RPF		0	70	61.4	0	0	0	0
	PVC		0	0	8.6	70	0	0	0
	Plastic Waste		0	0	0	0	70	0	0
	Housing Waste		0	0	0	0	0	50	0
	A S R		0	0	0	0	0	0	70
Total Charge (kg/hr)			70	70	70	70	70	50	70
Auxiliary fuel	Coke (kg/hr)		0	0	0	12	0	16	4
	LPG (Nm^3/hr)		3.2	2.5	2.9	3.0	3.3	2.6	2.5
Oxygen Blowing (Nm^3/hr)			52.1	65	62.9	64	65.8	54	48
Top Gas Volume (dry-Nm^3/hr)			136	190	174	168	195	149	140
Top Gas Temperature (K)			1423	1476	1518	1479	1504	1472	1483
Top Gas Composition (%) (except HCl)		CO	22	30	28	27	35	38	29
		CO_2	25	9	10	19	9	22	12
		H_2	12	31	27	24	26	12	22
		N_2	41	30	35	30	30	28	37
Slag Tapping Rate (kg/hr)			7.5	3.6	4.0	1.9	1.1	0.5	29.0

4.3. *Dioxin Emission*

Figure 6 shows influence of chlorine content in waste samples for dioxin emission. As a result of gasification in the high temperature reduction atmosphere and rapid gas quenching, the concentrations of dioxins of the off gas after gas treatment were kept under 0.01ng-TEQ/Nm^3 nevertheless plastic waste including polyvinyl chloride contain much chlorine which is one of constitutive element of dioxins.

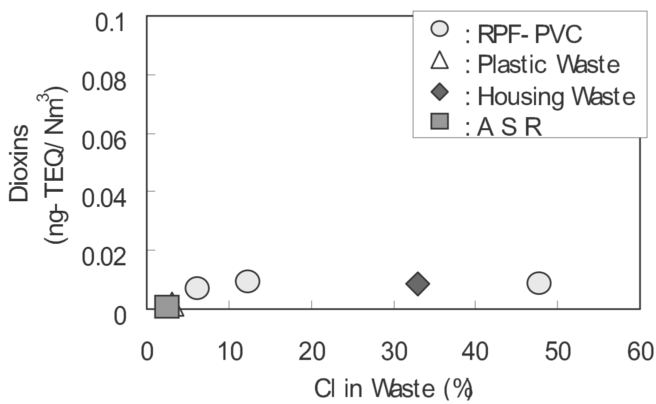

Figure 6. Influence of chlorine content for dioxin emission.

4.4. *Chlorine Recovery*

Figure 7 shows conversion ratio of chlorine into hydrogen chloride. Most of the chlorine in wastes converted into hydrogen chloride. The produced hydrogen chloride will be collected as hydrochloric acid and recycled in the case of using plastic waste including much PVC. Test to collect hydrochloric acid and to refine the collected hydrochloric acid were conducted. These results were introduced later.

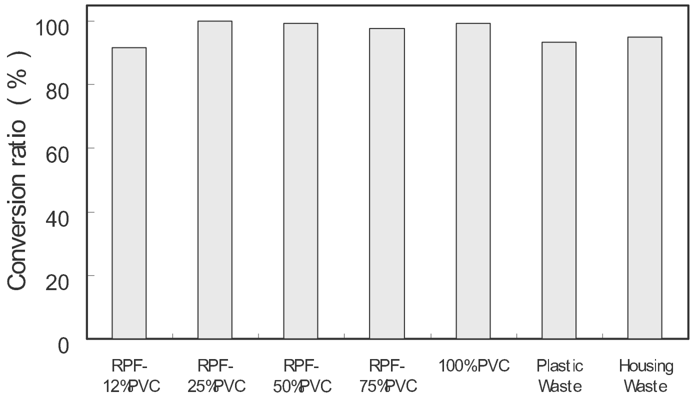

Figure 7. Conversion ratio of chlorine into hydrogen chloride.

4.5. *High-calorie Gas*

The main components of the product gas are CO and H_2 as shown in Table 3. Therefore, this system can produced high calorie gas. Product gas calorie of commercial furnace will be higher than that of the 2ton/day bench furnace because heat loss ratio will be decreased. Figure 8 shows calculation results of the product gas composition and gas calorie in the

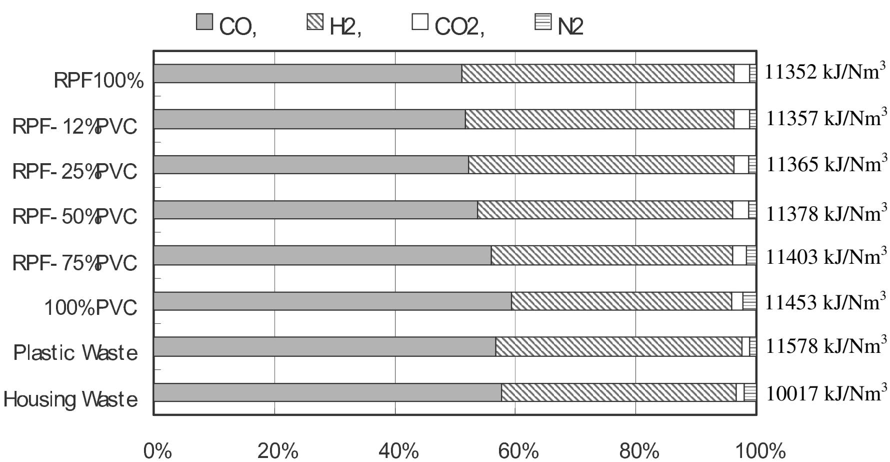

Figure 8. Product gas compositions in 50 ton/day furnace except HCl.

furnace with capacity of 50 tons/day. The gas calorie will be higher than 10000kJ/Nm^3. Figure 9 shows heat balance in 50 ton/day-commercial size furnace. The conversion ratio of waste calorie into energy gas (=Product gas energy / Input energy) will be 78% in the case of using actual plastic waste. This indicates that efficiency of heat recovery is very high. The produced energy gas can be recycled for high-efficiency power generating system by using a gas engine or turbine.

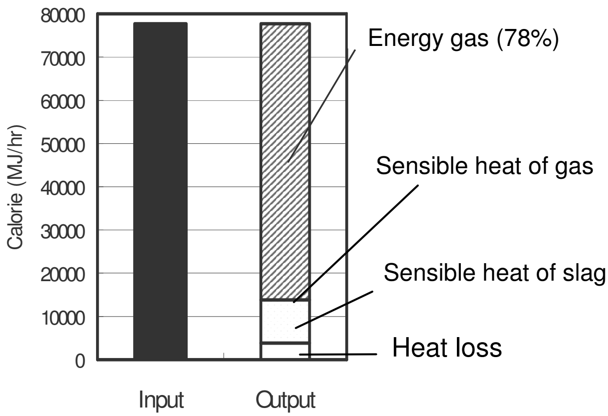

Figure 9. Heat balance in 50 ton/day furnace.

Table 4. Slag leaching test results (mg/L).

	Dried Municipal Waste	100% PVC	Plastic Waste	Housing waste	ASR	Standard Value
Cd	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cr^{+6}	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
T-Hg	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Pb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
As	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Se	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

4.6. *High Quality Slag*

Main components in produced slag are CaO, SiO_2 and Al_2O_3, and there is very little chlorine content. The amounts of heavy metals in the slag are very little because the heavy metals such as Cd, Hg, Pb, As and Se easily become volatile and concentrated in the generated gas or dust as a result of the smelting in the condition of a high temperature and reduction atmosphere. Thus the ratio of such heavy metals moving into slag is very small. Therefore, the heavy metals in the slag satisfy all of the Japanese standards for the leaching test as shown in Table 4 and the safety of the slag to be used for roadbed is very high.

Furthermore, heavy metals moving into dust can be used for raw materials of non-ferrous metals.

4.7. *Refining Test of Crude Hydrochloric Acid*

Conversion ratio of chlorine in wastes into hydrogen chloride was achieved to 90% or more as shown in Figure 7. To clarify possibility of chlorine recycling, a system to collect hydrochloric acid was installed. In this system, the hydrogen chloride was cooled by sprinkle water and collected as crude hydrochloric acid. However, impurities such as F, SO_4^{2-}, PO_4^{3-}, Zn, Ca, Sn and Pb were contained in the collected hydrochloric acid. Test to refine the crude hydrochloric acid was conducted. Five kinds of simulated hydrochloric acid solutions were prepared. The simulated hydrochloric acid solutions contain impurities such as metal, F, SO_4^{2-}, PO_4^{3-} as shown in Table 5. A system to refine the hydrochloric acid separated these impurities. Table 6 shows refining test results. The impurities in the refined hydrochloric acid satisfy all of the permissible level.

5 Design of Commercial Plant

This system was accepted for three commercial plants which have capacity of 132 tons/day (2 units of 66 tons/day) based on municipal waste in Tosu, Japan and 100 tons/day based on industrial waste in Yamaguchi and Kashima, Japan. The commercial plants were designed by using a 3-dimensional mathematical simulation model. The above-mentioned commercial plants have been operating at full capacity after start-up operation in 2004.

Table 5. Impurity contents in simulated hydrochloric acid solutions (25wt% HCl).

		1 Metal	*2* F	*3* SO_4^{2-}	*4* PO_4^{3-}	*5* F & Metal
F	mg/L	-	160			170
	mg/kg-HCl	-	615			654
SO_4^{2-}	mg/L	-		4800		
	mg/kg-HCl	-		18462		
PO_4^{3-}	mg/L	-			2300	
	mg/kg-HCl	-			8846	
Zn	mg/L	620				660
	mg/kg-HCl	2385				2538
Ca	mg/L	2200				2300
	mg/kg-HCl	8462				8846
Sn	mg/L	79				84
	mg/kg-HCl	304				323
Pb	mg/L	2100				2300
	mg/kg-HCl	8077				8846

Table 6. Impurity contents in crude and refined hydrochloric acid (mg/kg-HCl).

		1 Metal	*2* F	*3* SO_4^{2-}	*4* PO_4^{3-}	*5* F & Metal	*Permissible Level*
F	Crude	-	615	-	-	654	-
	Refined	-	1.1	-	-	< 0.5	< 1 - 5
SO_4^{2-}	Crude	-	-	18462	-	-	-
	Refined	-	-	0.29	-	-	< 1 - 5
PO_4^{3-}	Crude	-	-	-	8846	-	-
	Refined	-	-	-	< 0.5	-	< 1 - 5
Zn	Crude	2385	-	-	-	2538	-
	Refined	< 0.03	-	-	-	< 0.03	< 1
Ca	Crude	8462	-	-	-	8846	-
	Refined	0.43	-	-	-	0.78	< 1
Sn	Crude	304	-	-	-	323	-
	Refined	< 0.03	-	-	-	< 0.03	< 1
Pb	Crude	8077	-	-	-	8846	-
	Refined	< 0.06	-	-	-	< 0.06	< 1

6 Conclusions

More than 3,000 million tons of waste is generated in Europe every year, and total waste quantities are continuing to increase in most European countries [4]. PVC waste accounts for a total of about 15% of all plastic waste in the European Union (EU) [5], and PVC production is increasing, confronting future generation with rising amounts of PVC waste [6]. The number of scrapped cars in Europe is increasing, and the quantity of waste from scrapped cars is estimated at about 10 million tons [6]. A total increase of 124% in the number of scrapped cars is projected between 2000 and 2015 [4].

The Sumitomo Metals’ gasification and smelting system using iron-making and steel-making technologies can steadily gasify and smelt industrial waste such as plastic waste including polyvinyl chloride, automobile shredder residue, soil and so on the same as municipal waste. In this system, strong smelting ability and strong separation ability can produce dioxin-free high-calorie purified gas and heavy metal-free high quality slag. Furthermore, most of the chlorine in the plastic waste including PVC was converted into hydrogen chloride that is recovered as chlorine and hydrochloric acid. There will be high heat and mass recovery, production of dioxin-free high calorie purified gas, and heavy metal-free high quality slag, and recovery of chlorine.

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THE STATISTICAL ANALYSIS OF HUMAN BEING — ENVIRONMENT RELATION

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A very concerning factor is that at the beginning of the XX-th century the economy destroys its support system using the main natural funds. However, the economical system is partially "blind". The system focuses on very different things regarding demand and supply, but is totally subjective, even ignorant, in the appreciation of the value of some other things such as pure water, fresh air or the beauty of mountains. In the present paper the author approaches some of the classical methods used in statistics for the analysis of human being-environment relation and proposes new ways of current analysis required for adopting optimal economical patterns and strategies. The main issues presented in this article are those related to: the impact of population over the environment, the statistical modulation of the human being-environment relation and the mathematical and statistical modulation of the relation between economical development and pollution.

1 The Impact of Population over the Environment

The concept of "population" includes elements such as persons' spatial affiliation, their demographic rate and medium hope of life, relationship between genders, welfare, health and education. The term of "eco-development" was imposed, like a complex relationship between the economical development and the environment, because the economical development takes place within some ecological systems. Technology gave to man the possibility to change the environment in order to achieve his aims. The irrational exploitation of natural resources and their use without responsibility can lead to disastrous consequences for the ecological balance. There was a big concern of a great deal of economists for the needs of a population that quickly grows and the impact over the environment determined by their satisfaction. All the people agree that natural resources represent an important part of a developed economy, but the attention bestowed to these is insufficient. Even in present, in the official economical research, we will not find a higher preoccupation for environmental problems or the population growth in the undeveloped areas, from the economical point of view, such as The Indian sub-continental and The Sub-Saharan Africa, two regions where live in present about 2 millions people, from which more than 20% have an income less than \$1/ person.

This neglect of the environment is strange, because most of the people from the poor countries are farmers or shepherds. The population of rural area is 65% from the total population, in countries classified by Banca Mondiala like countries with very low incomes. The rate of agriculture is 30% in the internal growth product, in these countries. The poor countries are, to a great extent, countries with a subsistence economy where the persons with a low living standard assure their living with products got directly from the environment. The natural resources for these persons have an overwhelming importance. The countries strongly industrialized are to the opposite pole, where the main risk is the super-pollution. Industry spreads in the atmosphere and discharges in water big quantities of residua that deteriorates the structure of troposphere and continentals water. Residua and garbage stored on the ground are added to these, which reach to water. Synthetic detergents, insecticides or noxious substances that, through infiltrations, reach to the ground water-bearing bed, negatively modifying the composition of drinking water, spoil the water quality. Seas and oceans pollution endangers not only the own biological balance but also the life of living organisms including the humans. The life quality, that is an operational concept for checking the life conditions of human needs, has a big importance. As a result, prevention and control of the environment pollution are "sine-qua-non" conditions for a good health of population maintenance. The rate of agriculture is 30% in the internal growth product, in these countries. The poor countries are, to a great extent, countries with a subsistence economy where the persons with a low living standard assure their living with products got directly from the environment. The natural resources for these persons have an overwhelming importance. The countries strongly industrialized are to the opposite pole, where the main risk is the super-pollution. Industry spreads in the atmosphere and discharges in water big quantities of residua that deteriorate the structure of troposphere and continentals water. Residua and garbage stored on the ground are added to these, which reach to water. Synthetic detergents, insecticides or noxious substances that, through infiltrations, reach to the ground water-bearing bed, negatively modifying the composition of drinking water, spoil the water quality. Seas and oceans pollution endangers not only the own biological balance but also the life of living organisms including the humans. The life quality, that is an operational concept for checking the life conditions of human needs, has a big importance. As a result, prevention and control of the environment pollution are "sine-qua-non" conditions for a good health of population maintenance.

2 Statistical Methods in Analyzing the Relationship Human-Environment

2.1. *Method of Structural Coefficients in Analyzing the Relationship Human-Environment*

We will focus our attention on the analysis of variable "expenses for environmental protection". We will note: C_t - total expenses for environmental protection; C_c - current expenses for environmental protection, and C_i - investments expenses for environmental protection. The total expenses are given by the relation:

$$C_t = C_c + C_i \tag{1}$$

The structural coefficients of the two components of total expenses will have the following formula:

$$K_1 = \frac{C_c}{C_t}; K_2 = \frac{C_i}{C_t}; K_1 + K_2 = 1. \tag{2}$$

Analyzing in progress the value of total expenses, we will use the following notation: C_{t_0} − value of total expenses in year "0", and C_{t_1} − value of total expenses in current year "1". The dynamics index is:

$$i^{C_t}{}_{1/0} = \frac{C_{t_1}}{C_{t_0}} = \frac{C_{c_1} + C_{i_1}}{C_{c_0} + C_{i_0}}, \tag{3}$$

and the rhythm of dynamics:

$$r^{C_{t1/0}} = \frac{C_{t_1} - C_{t_0}}{C_{t_0}} 100 = \left(i^{C_{t1/0}} - 1\right) 100. \tag{4}$$

The contribution of each structural element to the general dynamics of total expenses will be:

$$A^{C_c}{}_{1/0} = \frac{C_{c_1} - C_{c_0}}{C_t} \cdot 100 \tag{5}$$

$$A^{C_i}{}_{1/0} = \frac{C_{i_1} - C_{i_0}}{C_t} \cdot 100 \tag{6}$$

$$r^{C_t}{}_{1/0} = A^{C_c}{}_{1/0} + A^{C_i}{}_{1/0} \tag{7}$$

These indicators, as relative measures of structure, can be used in determining the proportion of contributions within the rhythm of the value:

$$P_{C_c} = \frac{A^{C_{c1/0}}}{r^{C_{c1/0}}} 100 \tag{8}$$

$$P_{C_i} = \frac{A^{C_{i1/0}}}{r^{C_{i1/0}}} 100 \tag{9}$$

$$P_{C_c} + P_{C_i} = 100\% \tag{10}$$

This method can be used for each type of indicators that characterize the relationship human- environment.

2.2. *Method of the matrix calculation in the statistical analysis of the relationship human- environment*

We suppose that we have, for the same indicator-total expenses for the environmental protection- the following informational table (see Table 1).

Table 1. Total expenses for the environmental protection.

Field:	Total expenses for:				
	The prevention and control of pollution	Environmental protection	Research-development-training	General environmental management	………… …
Agriculture	c_{11}	c_{12}	c_{13}	c_{14}	c_{1m}
Forestry	c_{21}	c_{22}	c_{23}	c_{24}	c_{2m}
Extractive industry	c_{31}	c_{32}	c_{33}	c_{34}	c_{3m}
Processing industry	c_{41}	c_{42}	c_{43}	c_{44}	c_{4m}
Waste recovery	…..	……	……	…..	…...
Electric energy	…..	..….	………	…….	……..
Gas and water	…..	…..	…...	…..	…..
Transport and storage	…..	…..	……	…..	…..
Public administration	…..	…..	……	…..	…..
Drain	…..	…..	…..	…..	…..
Scavenging	…..	……	……	……	…..
Scientific research	……	……	……	……	……
Other activities	…..	…..	……	…..	…..
…………	c_{n1}	c_{n2}	c_{n3}	c_{n4}	c_{nm}

We note with $C_t = (c_{ij})_{n \times m}$, $i = \overline{1,n}$, $j = \overline{1,m}$, the matrix of total expenses, *i* representing the categories of expenses for environmental protection, *j*- the fields. The matrix of the averages on lines, that will illustrate total averages on fields, is:

$$\frac{1}{m}\begin{pmatrix} \sum c_{1j} & \sum c_{1j} & \ldots\ldots & \sum c_{1j} \\ \sum c_{2j} & \sum c_{2j} & \ldots\ldots & \sum c_{2j} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ \sum c_{ij} & \sum c_{ij} & \ldots\ldots & \sum c_{ij} \end{pmatrix} = \begin{pmatrix} \bar{c}_1 & \bar{c}_1 & \ldots\ldots & \bar{c}_1 \\ & & & \\ & & & \\ \bar{c}_1 & \ldots\ldots & \ldots\ldots & \bar{c}_n \end{pmatrix} \tag{11}$$

The matrix of the averages on columns that point out the average of each category of expenses, for all the fields is:

$$\frac{1}{n}\begin{pmatrix} \sum c_{i1} & \sum c_{i2} & ..... & \sum c_{im} \\ \sum c_{i1} & \sum c_{i2} & ..... & \sum c_{im} \\ ..... & ..... & ..... & ..... \\ \sum c_{i1} & \sum c_{i2} & ..... & \sum c_{im} \end{pmatrix} = \begin{pmatrix} \overline{c}_1^{'} & \overline{c}_2^{'} & ..... & \overline{c}_m^{'} \\ .... & ..... & ..... & .... \\ ..... & ..... & ..... & ..... \\ \overline{c}_1^{'} & .... & .... & \overline{c}_n^{'} \end{pmatrix} \qquad (12)$$

The deviations on lines d^l (deviations of the total expenses from their average on fields) are given by the difference:

$$\begin{pmatrix} c_{11} & c_{12} & ... & c_{1m} \\ c_{21} & c_{22} & ... & c_{2m} \\ ... & ... & ... & ... \\ c_{n1} & c_{n2} & ... & c_{nm} \end{pmatrix} - \begin{pmatrix} \overline{c}_1 & \overline{c}_1 & ... & \overline{c}_1 \\ ... & ... & ... & ... \\ ... & ... & ... & ... \\ \overline{c}_1 & .. & ... & \overline{c}_n \end{pmatrix} = \begin{pmatrix} d_{11}^l & d_{12}^l & ... & d_{1m}^l \\ d_{21}^l & d_{22}^l & ... & d_{2m}^l \\ ... & ... & ... & ... \\ d_{n1}^l & d_{n2}^l & ... & d_{nm}^l \end{pmatrix}. \qquad (13)$$

The deviations on columns d^c (deviations on components of the total expenses from their average for all the fields) are given by the difference:

$$\begin{pmatrix} c_{11} & c_{12} & ... & c_{1m} \\ c_{21} & c_{22} & ... & c_{2m} \\ ... & ... & ... & ... \\ c_{n1} & c_{n2} & ... & c_{nm} \end{pmatrix} - \begin{pmatrix} \overline{c}_1^{'} & \overline{c}_2^{'} & ... & \overline{c}_m^{'} \\ ... & ... & ... & ... \\ ... & ... & ... & ... \\ \overline{c}_1^{'} & .. & ... & \overline{c}_m^{'} \end{pmatrix} = \begin{pmatrix} d_{11}^c & d_{12}^c & ... & d_{1m}^c \\ d_{21}^c & d_{22}^c & ... & d_{2m}^c \\ ... & ... & ... & ... \\ d_{n1}^c & d_{n2}^c & ... & d_{nm}^c \end{pmatrix}. \qquad (14)$$

The matrix of the square of deviations on lines is:

$$\begin{pmatrix} (d_{11}^l)^2 & (d_{12}^l)^2 & ... & (d_{1m}^l)^2 \\ (d_{21}^l)^2 & (d_{22}^l)^2 & ... & (d_{2m}^l)^2 \\ ... & ... & ... & ... \\ (d_{n1}^l)^2 & (d_{n2}^l)^2 & ... & (d_{nm}^l)^2 \end{pmatrix}. \qquad (15)$$

The matrix of the square of deviations on columns is:

$$\begin{pmatrix} (d_{11}^c)^2 & (d_{12}^c)^2 & ... & (d_{1m}^c)^2 \\ (d_{21}^c)^2 & (d_{22}^c)^2 & ... & (d_{2m}^c)^2 \\ ... & ... & ... & ... \\ (d_{n1}^c)^2 & (d_{n2}^c)^2 & ... & (d_{nm}^c)^2 \end{pmatrix}. \qquad (16)$$

The sum of the square of deviations on lines is:

$$\begin{pmatrix} \sum_{j=1}^{m} (d^{l}_{1j})^2 \\ \sum (d^{l}_{2j})^2 \\ . \\ . \\ . \\ \sum (d^{l}_{nj})^2 \end{pmatrix}. \tag{17}$$

The sum of the square of deviations on columns is:

$$\left(\sum_{i=1}^{n} (d^{c}_{i1})^2, \quad \sum (d^{c}_{12})^2 .... \quad \sum (d^{c}_{im})^2 \right). \tag{18}$$

The dispersion on lines:

$$\begin{pmatrix} \sum_{j=1}^{m} (d^{l}_{1j})^2 \\ \sum (d^{l}_{2j})^2 \\ . \\ . \\ . \\ \sum (d^{l}_{nj})^2 \end{pmatrix} \left(\frac{1}{m}, \frac{1}{m} ....., \frac{1}{m} \right) = \begin{pmatrix} \sigma^2{}_1 & \sigma^2{}_1 ...... \sigma^2{}_1 \\ \sigma^2{}_2 & \sigma^2{}_2 ...... \sigma^2{}_2 \\ . & \\ . & \\ \sigma^2{}_n & \sigma^2{}_n ...... \sigma^2{}_n \end{pmatrix}. \tag{19}$$

The dispersion on columns:

$$\left(\sum_{i=1}^{n} (d^{c}_{i1})^2, \quad \sum (d^{c}_{12})^2 .... \quad \sum (d^{c}_{im})^2 \right) \begin{pmatrix} \frac{1}{n} \\ \frac{1}{n} \\ . \\ . \\ \frac{1}{n} \end{pmatrix} = \begin{pmatrix} \sigma'^2{}_1 & \sigma'^2{}_2 ... & \sigma'^2{}_m \\ . & & \\ . & & \\ . & & \\ \sigma'^2{}_1 & \sigma'^2{}_2 ... & \sigma'^2{}_m \end{pmatrix}. \tag{20}$$

The matrix analysis can be continued with the construction of chronological series on the basis of these indicators, analysis of their dynamics as well as parameters estimation of regression equation, determination of the anticipated horizon and determination of the correlation coefficient and can be applied to other indicators, such as current expenses indicator for environment, investments expenses.

2.3. *Orders Correlation in Analyzing the Relationship Human-Environment*

We can determine the existence, the type and the intensity of the possible correlations between environment indicators and demographic indicators by means of coefficients of orders correlation. We suppose that we have the following data regarding 10 counties where there was registered an exceed of the maximum admissible concentrations of pollutant substances in the air and the death at the age of 1 year old to 1000 living born, in the same towns.

Table 2. Comparison between maximum available concentration frequency- powders in suspension and death at the age of less than 1 year at 1000 living born.

County	Maximum available concentration frequency- powders in suspension	Death at the age of less than 1 year at 1000 living born	County	Maximum available concentratio n frequency- powders in suspension	Death at the age of less than 1 year at 1000 living born
Arad	61,80	17,6	Iași	33,9	21,3
Bistrița Năsăud	26,31	13,8	Olt	22,2	14,7
Brașov	31,04	15,9	Timiş	26,57	17,9
Caraş-Severin	19,48	12,7	Vrancea	42	15,3
Constanța	33.3	25,6	Galați	17,59	16,6

Using Spearman's coefficient will analyze the possible correlation between the two variables: deaths at the age of less than 1 year for 100 living born- resultant variable, maximum available concentration frequency- powders in suspension- factorial variable. The calculation is:

$$C_S = 1 - \frac{6\sum d^2{}_i}{n(n^2-1)} . \tag{21}$$

The data necessary for calculation are systematized in Table 3.

So we have $C_S = 1 - 0{,}45 = 0{,}55 > 0$, direct correlation and enough intense. We showed that there is a direct relation between the pollution degree of a geographical area and the number of deaths at an age of less than 1 year in that place. The parametric correlation and the regression for determining the connections between different indicators such as concentration of pollutant substances in the water of certain geographical areas, afforested areas and the child death rate for the respective geographical areas. The informational contribution is obvious.

Table 3. The data necessary for calculation.

X	Y	R_x	R_y	$d_i = R_x - R_y$	$d^2{}_i$
17,59	16,6	1	6	-5	25
19,48	12,7	2	1	1	1
22,2	14,7	3	3	0	0
26,31	13,8	4	2	2	4
26,57	17,9	5	8	-3	9
31,04	15,9	6	5	1	1
33,3	25,6	7	10	-3	9
33,9	21,3	8	9	1	1
42	15,3	9	4	5	25
61,8	17,6	10	7	3	9

3 Statistical and Mathematical Pattern-Making of the Relationship Economical Development-Pollution

Victor Platon [4] presents the following alternative of mathematical pattern- making of the relationship economical development- pollution. It starts from the production function:

$$Q = f(K,L), \tag{22}$$

where are: *K*- the capital and *L*- the labor forces.

The volume of pollutant emissions depends on the consumption level and production level by means of some specific coefficients, so we have:

$$E_p = q(Q - B) + p \cdot Q, \tag{23}$$

where is: *B* – the economic benefit.

These specific coefficients indicate the intensity of pollution when a certain good or service is produced. These can be expressed in tons or kilograms for a certain value of the production in lei or dollars. The density of the polluted persons from the environment, noted by *D*, will depend on the level of pollutant emissions, the dispersion volume or surface of pollutants *V*, the absorption capacity of the environment *m*, the existence of anti-pollution equipments *k* and the capacity of anti-pollution equipment to retain the pollutant emissions *h*:

$$D = \frac{E_p}{V} - h \cdot k_r - m \cdot \tag{24}$$

If the density of the pollutants from the environment is constant then the quality of environment is optimal:

$$\frac{dD}{dt} = 0 \cdot \tag{25}$$

The author supposes that, at that moment, there is no pollution or pollutant equipments and nor economical benefits. In this case the maximal production that can be realized without the modification of environmental quality is:

$$Q_{\max} = (m + h \cdot K_r)\frac{V}{q+p}, \tag{26}$$

where is: K_r - the assets due to anti-pollutant-equipments.

Supposing that this time there is pollution, pollutant equipments and economical benefits, we note: *C*- expenses generated by the anti-pollution actions, *B*- economical benefits as a result of the actions for the environmental production, *P*- economical and social losses as a result of the pollution. The expenses will increase as one goes along, an improvement of environmental quality will be obtained, these expenses determining a consumption of fixed and net current assets:

$$C = f(K_r, D) \cdot \tag{27}$$

The total expenses will increase up to a certain extent and then will diminish. The diminishing is due to the fact that the reduction of factor *D* at quality superior levels of environment generates small reductions of pollutant effects and small increases of benefits. The economical benefits resulted from anti-pollutant actions will increase with the same value the economical losses were reduced, *P*, provoked by pollution. Factor *D* has to be diminished up to the moment where the economical and social losses determined by the pollution not annihilated disappeared. It is observed that the **optimum value** is obtained when the report $\frac{B}{C} \to \max im$ or $B - C$- maxim. The maximum difference is when $B' = C'$.

The economical units have to respect the legal standards regarding the environmental protection. This fact demands current expenses (for the purification stations, consumption of raw material, consumption of energy, fuel, and damping) and investments expenses. The relation that does the equating of all the expenses is:

$$C_n = C_c + I \cdot q, \tag{28}$$

where are: C_c- annual anti-pollutant current expenses, *q*- standardized coefficient of efficiency and *I* - total investments for anti-pollutant actions.

In the anticipated analyses we have to take into account that:

$$B_n - \Sigma[B - C_n] \to \max im,$$

where are: B_n - the total net benefits as a result of the anti-pollutant actions, *B*- the economic benefit as a result of anti-pollutant actions, at the level of economical unit and

C_n - the expenses for environmental protection equivalent as nature. For the calculation of total benefits as a result of pollution reduction, the benefits resulted from the quantitative, qualitative and in the same time quantitative-qualitative improvement of the production and environment factors. We will have:

$$B_t = B_{\Delta q} + B_{\Delta c} + B_{\Delta q \cdot \Delta c},$$

where are: B_t - the total benefits as a result of pollution reduction for one production or environment factor and $B_{\Delta q \cdot \Delta c}$ benefit obtained through the quantitative and qualitative increase, in the same time, of the analyzed factor.

The pattern making of the relationship between economical development and pollution can be extended through determination equations of the balance by maintenance of environmental quality, taking into consideration the effect of politics over the equilibrium point, the influence of the anti-pollutant equipments fir establishing the maximum productive level, enlargement of analysis field and its elaboration through systematical correlation of information. This is necessary for politics proved scientifically for protecting the environment.

4 Conclusion

The very fast development of technical and scientific revolution both in the industrialized countries and in the developing ones, determined big concerns caused by the problems of the century we live in, such as 5 billions of persons whose annual rate of growth is 83 millions, population that together with the technological progress provoked unprecedented ecological modifications motivated by the people's desire for a high living standard and for satisfaction of more various and more higher needs. The protection of environment and the quantitative measurement of environmental modifications have to be one of the major contemporary concerns. The paper presents some methods of statistical and mathematical pattern making of the relationship human- environment, without completely dealing with this issue.

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PHYTOREMEDIATION NEW TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT*

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Phytoremedation is the technology in which we use green plants with an aim to remove polluting substances from human environment and to transform them into harmless forms. Phytoremediation of lead contaminated soil is Authors research. For Phytoremediation contaminated soil we used phytoaccumulator plant (*Brassica juncea)*. Experiments have proved that usage of synthetic chelates in the phytoremediation process increased lead (heavy metals) uptake by plants.Phytoremediation is innovative cleanup technology for Sustainable Development which cleans contaminated soil using hyperaccumulator plants .

1 Introduction

1.1. *The Concept Sustainable Development*

Concept of Sustainable Development is social development of human race in accordance with economic development and environmental protection. The Rio Earth Summit in 1992 resulted in a global plan for action for sustainable development – Agenda 21; Recommendations have been set for developed and developing nations regarding to sustainable development strategies in various areas, such as clean air and water, water supply, energy, land use, housing, waste treatment, transportation, and health care.

Orientation for the concept of the Sustainable Development is participation the Republic of Serbia in process “Environment for Europe”.The future generations are dependent on nowadays. Sustainable development in future means reduction of use of the fossile fuel, such as coal, oil and gas with necessarily effort for environmental protection.

On the global and local plan we need technologies for decreasing greenhouse gas emission and enviroment revitalization. We propose alteration for decrease environmental damage and exchange the fossile fuels with restorable energetically resources (wind or solar energy) in future and development our society in sustainable direction.

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1.2. *Description of the problem*

Anthropogenic activities-generate pollutations.For many years, human activities connected to industry, energy production, mineral exploitation and distribution and traffic, etc caused, and still causing, production and storage of dangerous polluting substances. Pollutations come to air, water, soil. Pollutations from the air, gaseous or aerosol like, in time mostly come to soil and after that to underground and ground waters. Soil is being irreversibly lost and degraded as a result of increasing and often conflicting demands from nearly all economic sectors. The main problems are irreversible losses due to soil sealing and erosion, continuing contamination from local and diffuse sources, acidification, salinization, compaction and desertification. We support the use of market based and economic instruments, but promotion of economic growth and environmental protection through improving efficiency and sustainability in the use of resources and production processes.

Connected to human's and animal's health pollutations could be toxical, cancerogenic, teratogenic, allergogenic, mutatogenic, bio-accumulative. In time, depending to substratum, in wich pollutations are, polluting materials are degradated by different speed.

Soil pollutations, as researches on territory of the Republic of Serbia show, include: heavy metals, pesticides, PCBs, PAHs, radio-nuclides, acid rains, wasted waters, particles of dust, coal, minerals, pathologenic organisms, etc. Under influence of pollutations, soil does self-purification, until it losses that ability, by destruction of the soil or furthermore to temporary or permanent expulsion from use. In that way comes up reduction of healthy drinking water, reduction of territory convenient for agricultural use, reduction of terrain convenient for production healthy and safe food.

If we do not pay attention on degradation of the soil, especially on contamination by heavy metals, pesticides, radio-nuclides, and other dangerous materials from different sources, it could be possible, very soon, to have "chemical time bomb", compared with appearance of cancer metastasis in human organism [1].

Heavy metals like cadmium, mercury, nicle, lead, uranium, copper, iron, manganese, zinc, etc. are toxically substances wich include in food chain, and perform high risk for biodiversity in long term period. Risk could be different: deteriorated human's, animal's and plant's health, object damage, or structures on the ground, contamination of underground and ground waters wich are connected with the soil.

Influence of toxic metals dependes on their conditions and shapes, which causes theirs behavior in soil. For example As and Se are more mobile in alkal pH while Hg, Pb, Cd and Zn are more mobile in acid pH of soil [2]. Influence of the soil pH on the radio-nuclides and organic compounds is relatively specific. Answer of the scientists on problems connected to soil contamination and wasted waters are solutions for the decontamination. In that way, the natural processes connected to capability of higher plants, are used for remediation-cleaning up the soil and wasted waters. Processes in the higher plants, caused by presence of pollutations, on the observed terrain, point to high potential for cleaning up through plants. These plants Phytoremediators, wich are able to accumulate metals and radio-nuclides in the above ground part of the plant, realizes the possibility for soil and technogenic pollutations decontamination.

After the use of plants to clean-up the terrain, decontaminated soil could be used in agriculture. Phytoremediation is new technology based on the use of higher plants for cleanup process of contaminated environment.Fundamental and applied researches have unequivocally demonstrated that selected plant species have potential to remove, degrade, metabolize, or immobilize a wide range of contaminants [3]. Phytoremediation, as well as the Sustainable Development is based on the implementation of three fundamental components: environmental protection, economic growth and social equality. Phytoremediation for Sustainable Development is based on the reduction of the contaminated terrains.

Phytoremediation in the Republic of Serbia is support to Sustainable Development in the reduction of the pollution, and cleaning-up places contaminated with waste materials is subject-matter of researches done by author of this work.Necessity for decontamination of the terrain-places contaminated by waste materials in R. Serbia exists. Solution through use of the Phytoremediation is intruded, as the alternative to expensive and aggressive processes for environmental decontamination. By application of the Phytoremediation, we achieved:

1. Reduction of the risks from heavy metals in the soil.
2. Reduction of risks for water resources.
3. Reduction of human's health risks.

Menagers of Occupation Battery Factory Sombor, which is surrounded by soil contaminated by lead and heavy metals., decided that contaminated soil, should be cleaned up [4]. Fundamental and applied research have unequivocally demonstrated that selected plant species possess the genetic potential to remove, degrade, metabolize, or immobilize a wide range of contaminants including lead and others heavy metals.

Through the Phytoremediation**,** [5], extracted arsenic, from ash deposit of Kostolac thermo electrical power plants, by using the fern, in 2002. Adoption of arsenic by plants grown on the Kostolac thermo electrical power plants ash. We investigated quantity of arsenic in bottom coal ash from thermo electrical power plant Kostolac, and uptake of arsenic in plants (*Calamagrostis epigeios*), (*Tusilago fanfara*), (*Sysibrium orintale*), in coal ash area Kostolac.

To avoid propagation of weedy species, crops are in general preferred although some crops may be too palatable and pose a risk to grazing animals. Reduce the risks to human health through pollution prevention and control [6]**.** To start inducted, by using plants phytoaccumulators and helath reagents, phytoaccumulations of toxic metals (Pb, Cu, Zn, Cr , Mn), from soil, ex situ 2000.- 2001. In that way, effects and possibility for decontamination by the Phytoremediation were strengthened. Used helathy reagents: citric acid and EDTA increased lead accumulation by several tenth times.

Team **[7]** applied Phytoextraction for Cleaning-up Uranium- contaminated soil. Phytoextaction as their specially form, establishes on the hyperaccumulative capability of plants. The oil rape (*Brassica napus var Banacanka*) demonstrated hyperaccumulative capability.

We came to know that soil pH has large influence on accumulation and translocation of uranium from the soil. By reduction of pH on the amount of 5, uranium accumulation is intensived by 14 times. Helath factors as citric acid, acetiqum acid, EDTA and HEDTA increase uranium accumulation by several hundreds times.

Sanitary Ecology Society of Belgrade, [8] (2004/2005.) applied Phytoremediation for Cleaning of heavy metals from the soil on terrain around Foundry Livnica Rakovica, Belgrade, R.Serbia. Part of the project is introduction of new ways of sustainable usage of the soil and water in the interaction of the plants, by the Publisher[a].

2 Implementation of the Phytoremediation

The Model Researching:

- Environmental identification of the area.
- Chemical analysis of the soil before application of the phytoremediation.
- Sowing the plants phytoaccumulators.
- Usage of agricultural and technical measures and inspection of vegetative development (Usage of helath factors).
- Picking up and drying the plants.
- Chemical analysis of soil after finishing Phytoremediation.
- Chemical analysis of green leaves of plants.
- Determination of coefficient of concentracion CF of plants.

Gathered material is dried in shadow and draft without sun light presence. After sample preparation content of heavy metals is determined by AAS atomic absorption spectrophotometry.

Important factors as starting basis for successful application of the Phytoremediation are:

- Observation of the orographic and climate factors of the area.
- Correct plant selection.
- Chemical characteristics of the soil.
- Determination of pH value.
- Determination the humus content.

Identification of the area, to determinate parameters of the soil and heavy toxic metals. Phytoremediation of lead from the soil – The parallel researches: Research (1) and The Research (2). Inducted phytoextraction is understood as course of with the induction (addition of helath factors citric acid 1%). During 2000-2001, research of inducted or guided Phytoremediation ex situ on the soil from contaminated terrain, has been lead end

[a] http://www.rec.org/sector/default.html
http://www.saneko98.com /files/project

heavy metals by application of the plants from sp. Brassicacea- (Brassica juncea).The Research (2) Continual Phytoextraction is understood as course of the applied of the automatic Phytoremediation, without induction. Researchings were led on the contaminated soil in situ, during 2001. The Phytoaccumulation of lead and heavy metals from the soil (without addition of helath factors). Lead and heavy metals adoption from the soil by plant (*Brassica juncea*) is expressioned in mg/kg of dry matter. Results are represented as the lead contents in the parts of examined plant (*Brassica juncea*), after the Phytoremediation.

3 Results

The tables show results of Phytoremediation of lead from the contaminated soil, as the lead contents in the parts of examined plant (*Brassica juncea*) and lead contend in the plants after use of inductors of phytoextraction., lead content in the soil before and after phytoremediation, the lead content after application of continual phytoextraction. Research (1.) - Inducted phytoextraction, is shown in Table 1.

Table 1. The lead contents in the plants (*Brassica juncea*) (mg/kg), when helath factors were used.

Plants	lead	method
leaf	4888,72	AAS
stalk	4303,44	AAS
root	150,46	AAS
total	9342,62	AAS

Lead adoption from the contaminated soil by tested plant (*Brassica juncea*), expressioned in mg/kg, showes that (*Brassica juncea*) has accumulated lead in all its parts, totally 9342,62 (mg/kg).

The lead content in the soil,after application of the Phytoremediation in one harvest season, is reducted, compared to content before the Phytoremediation,is shown in Table 2.

Table 2. The Parallel review for the lead in soil before and after applied of the Inducted Phytoextraction.

Content of the lead	mg/kg
Content in the soil before	972,31
Content in the soil after	105,52

The lead content in the soil is reduced for more than 9 times, the Phytoremediation with using of induction (helath factors). Confirmation was got that high concentrations of accumulated lead in the plant had been achieved by application the citric acid 1%. Heavy metals and metalloids from the soil before the Phytoremediation (copper, zinc, manganese, chrome, nicle, arsenic, cadmium and mercury etc), are shown in Tables 3 and 4.

The total content of heavy metals and metalloids including Fe, in the soil 24399,17 (mg/kg). Phytoaccumulation of lead and toxic metals from the soil in situ, during 2001. The Research (2), Continual phytoextraction is shown in Table 5 and 6.

Total content of phytoaccomulated heavy metals, on the plants 897,77 (mg/kg) (*Brassica juncea)* -mostly translocated in the green leaves.

The lead content in the soil,after application of the Phytoremediation in one harvest season, is reducted, compared to content before the Phytoremediation, shown in Table 7.

Table 3. The content of heavy metals, in soil expressioned in (mg/kg).

metal	Pb	Cu	Zn	Cr
amount	1051,46	86,57	218,19	36,69
MAC.[a]	100	100	300	100

Table 4. The content of metals and metalloids, in soil expressioned in (mg/kg).

Mn	Ni	As	Cd	Hg
458,71	41,79	20,55	1,33	6,06
-	50	25	3	2

Table 5. The lead, mercury, zinc contents in the plants (*Brassica juncea*) (mg/kg), Continual Phytoextraction.

Plants	lead	mercury	zinc	method
leaf	1113,97	3,65	28,35	AAS
flower	26,19	7,35	44,35	AAS
root	7,16	3,54	25,55	AAS
stalk	7,37	4,02	25,22	AAS
total	154,69	18,56	123,47	

Table 6. The chrome, manganese, iron contents in the plants (mg/kg), Continual Phytoextraction.

Plants	chrome	manganese	iron	method
leaf	2,41	50,93	192,88	AAS
flower	2,21	18,61	127,29	AAS
root	0,99	6,29	134,31	AAS
stalk	5,77	6,43	60,09	AAS
total	11,38	82,26	514,57	

Table 7. The Parallel review for the lead in soil before and after applied of the Continual Phytoextraction.

Content of the lead	mg/kg
Content in the soil before	972,31
Content in the soil after	328,69

[a] Maximum permited concentrration

The lead content in the soil is reduced 3 times, the Phytoremediation with Continual phytoextraction. In these way of using of the Phytoremediation for lead adoption from the soil by plants, process haveto be repeated.

The Phytoremediation of lead from contaminated soil, is shown as the lead contents in the disposition of the parts of examined plant (*Brassica juncea*), after using Inducted Phytoextraction. The most of the lead Brassica juncea has accumulated and translocated in the green leaves, stalk and root, see Figure 1.

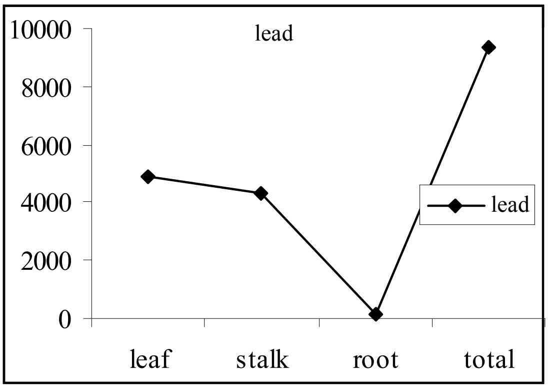

Figure 1. Disposition of the adopted lead in the plant phytoaccumulator.

The lead content in the soil is reduced for more than 9 times,after application of the inducted Phytoremediation (helath factors).The lead content in the soil, after application of the Phytoremediation in one harvest season, is reduced, compared to content before the Phytoremediation, see Figure 2.

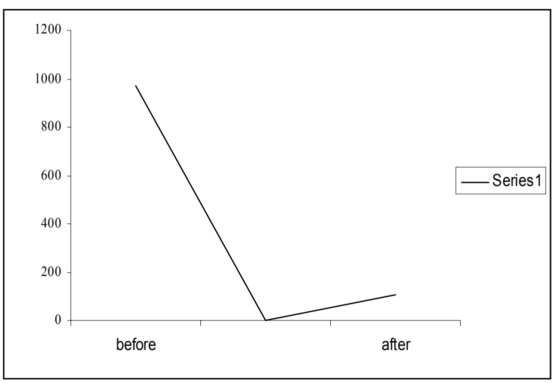

Figure 2. The lead content in the soil before and after of the Phytoremediation.

Heavy metals from the soil before the Phytoremediation (copper, zinc, manganese, chrome, nicle, arsenic, cadmium and mercury etc). The lead and mercury are higher than MAC.[a] , see Figure 3.

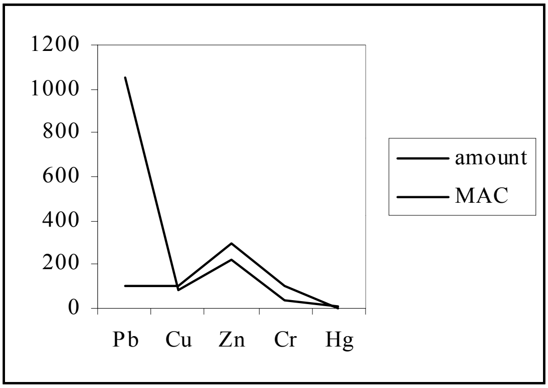

Figure 3. Heavy metalls from the soil (lead, copper, zinc, chrome, mercury).

Determinatet content of heavy metals and metaloids from the soil shows that this was contaminated soil, by lead and mercury before the Phytoremediation. The lead content in the soil is reduced for more than 9 times, when Phytoremediation was with induction (helath factors), see Figure 4.

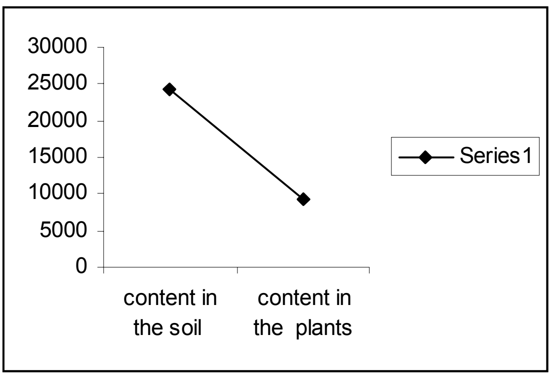

Figure 4. Reduced lead from the contaminated soil.

The lead content in the soil,after application of the Phytoremediation in one harvest season, is reduced, compared to content before the Phytoremediation.

[a] Maximum permited concentrration

4 Estimate and modeling from experiments

Results obtained from researchings could be used for determination of the coefficient of plant's concentration by using the next equation.

CF – (1.) plant's concentration factor:

$$CF = \frac{C_{L_{(Pb)}}}{C_{Z_{(Pb)}}}$$

$C_{L_{(Pb)}}$ -lead concentration in dry matter of biomass in plant remainders, at the and of the Research (1.) = 9342,62 mg/kg.

$C_{Z_{(Pb)}}$ -initial concentration of lead Research (1.) = 972,31mg/kg.

CF (1.) =9342,62 /972,31 = 9,61.

According to data from literature from Salt *et.al.* [9], CF plants concentration factor for lead for (*Brassica juncea*) is between one and ten.

Plants the Phytoremediators could be used on different environmental bases:for cleaning up the air, ground waters, waste waters, soil. For the decontamination was used plant sp. Brassica juncea. Also, researchings were performed with other plants the Phytoremediators (*Brassica napus, Helianthus annus, Clamagrostis epigeios, Tussilago farfara, Sysimbrium orientale*) on contaminated terrains.

According to the results of the researchings, application of the Phytoremediat on territory of R. of Serbia on areas new biotechnology could be recommended for further application in practice. Researchings led to knowledge that Brassica juncea possess ability for natural adaptation on the explored territory. In Serbia ex situ researchings of inducted Phytoremediation, for lead from the soil, tested plant Brassica juncea has shown excellent results.

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DETERMINATION OF LUBRICANT OIL QUALITY IN VEHICLES USING NEURAL NETWORK FOR ENVIRONMENTAL ISSUES*

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Lubricant oil consisting of petroleum, mineral and synthetic based will change its characteristics based on temperature and pH value that gradually downgrades its quality. For those reasons, maintaining lubricant viscosity can guarantee maximum ability in machine functions particularly in reducing friction, protecting as well as cleaning the engines. Currently, measuring vehicle's mileage and duration or either one does maintain lubricant viscosity. Unfortunately, these judgments are inaccurate because there are many other factors like pressure, shear stress, humidity and conductivity that may affect viscosity quality. In addition, improper treatment of used lubricant oil will greatly pollute the environment. This paper proposed one theory of determining viscosity quality with Neural Network (NN) modeling by introducing temperature, shear stress and pressure effects. One deterministic objective will be highlighted that is to develop NN modeling based on those three factors. NN modeling, an off-line system is explicitly designed with Backpropagation Algorithm and Multilayer Feedforward Network for learning process while its weight is calculated based on Nguyen Widrow number and Genetic Algorithm. There are 310 sample data, which divided into two sets; 149 data for training while 161 data for testing. The application performance has achieved up to 85.91% approaching real viscosity value. This research, as guidance for future research, aims to produce a user-friendly hardware for academic purposes and fulfill the needs of community. Finally, vehicle users will get real-time information from lubricant consumed for their vehicle.

1 Introduction

Lubricant oils are used in vehicles is particularly for reducing frictions and wears, and protecting as well as cleaning the engines. This research was conducted on a vehicle

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lubricant to investigate the effects it has on vehicle engines. A way of preventing the breakdown of an engine due to vehicle lubricant problems is to use a suitable lubricant that suits the engine requirements. This research† is an effort to study the vehicle lubricant and to further improves its quality by using a data identification method that can recognize the viscosity value of the lubricant and the substances it contains.

2 Research Background

2.1. *Lubricant Oil*

A lubricant is a blend of base oils and performance-enhancing additives as required by engines, gear box and other application areas. At the refinery plants, the crude oil is refined into gasoline, diesel, kerosene, LPG, naphtha and base stocks (Lube). This base stock is further processed, blended and strengthened with required properties to make different kind of lubricants [1]. The main purpose of lubricants is to lubricate moving parts of the vehicle to reduce friction, wear and tear by providing smoothing, and trouble free performance for increased length of time.

Currently, there is yet any equipment, which is capable to detect the quality of lubricant oil using NN especially in car engine. Lubricant oil should always be replaced at the intervals recommended by the maintenance manual as described by a manufacturer. These days the drain life of an engine oil is anywhere between 5000 to 15000 km (or even more) or six months to one year, whichever is first. In this paper, attention will be given on developing a sensor which is capable to detect the quality of lubricant oil based on the data given by user such as specification of oil, manufacturer, and periods of usages, by transferring all these data into computer and generate the result for the quality of lubricant oil [2].

2.2. *Oil Specification*

For satisfactory lubrication of the engine, the oil should possess some functional properties of which viscosity of oil is one of the most important properties, as it brings out the oil's capacity to lubricate. Viscosity is the measure of oil's resistance to flow. The oil viscosity is identified by its SAE's (Society for Automotive Engineer's) number. The thinner the oil, the lower its number, e.g. SAE 10 [1]. The numerical relates to viscosity at particular temperature and the alphabet 'W', indicates the oil's suitability for colder temperature. With the viscosity index improves, the viscosity increases at higher temperature and at lower temperature it does not increase significantly, thus achieving optimum viscosity at lower and higher temperature. Such oils are called multi-grade oils, for instance '20 W40' shows thinness at low temperature and thickness at higher temperature. However, there is other service classification of oil apart from viscosity, developed by API- (American Petroleum Institute), which indicates service characteristics. It is graded on a scale from SA (the lowest) to SL (the highest) [3].

2.3. *Environmental Issues*

The development of this user-friendly detector in contributing for optimization of lubricant oil used was indicated by a signal generated from computer. Significantly, this will optimize consumption of lubricant oil in vehicles and industrial machinery, save the cost of purchasing lubricant oil, lengthen the life span of lubricant oil reduce the operational cost of lubricant oil waste treatment, generate reusability of lubricant oil and hence, it is expected to reduce pollution caused by lubricant oil, and accomplished a clean and non-polluted environment.

3 Objectives

This research paper has two main objectives: First, is to propose a new car engine design with real-time viscosity data and secondly is to clarify results of NN in conjunction to three inputs of temperature, shear stress and pressure.

4 Methodologies

4.1. *Proposed design of car engine*

In order to gather the real-time viscosity data, this research was subjected to install a viscometer and a conductivity sensor to detect the viscosity and conductivity of lubricant oil on-line in car. Additional part of retrieved lubricant oil from car on the engine was built to connect the oil sample from engine to the viscometer. Collection of oil samples from engine was important, since obtaining a representative sample is one of the most prominent parts on scheduled oil analysis program. If a sample does not represent the true condition of the lubricant and component at the time of sampling, the reliability of both test results and its interpretation will be affected. The following points in Figure 1 indicate the location of detector to be installed.

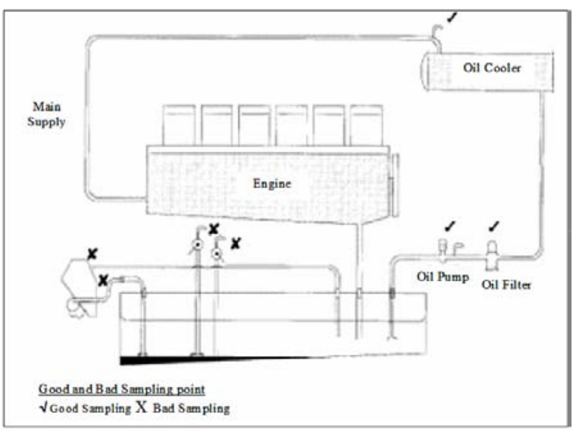

Figure 1. Proposed points retrieving sampling oil.

The connection from viscometer to computer involved an analog to digital converter. This converter will transfer the analog signal generate by viscometer and convert it into the digital form to be read by a computer. The 4-20 mA output is capable to generate the current which direct proportional to both parameters previously stated. These current represented the true condition of oil being detected. The transform of current into digital signal to be recognized by computer requires an interface of analog to digital converter. Figure 2 illustrates the connection of sensor to computer [4].

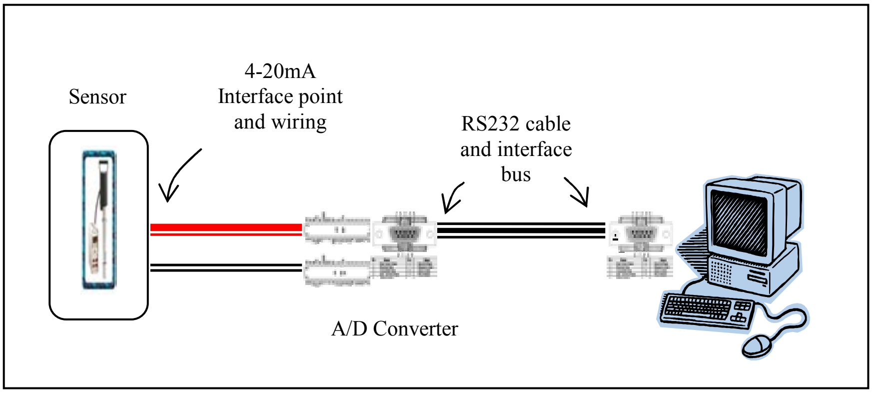

Figure 2. Connection Sensor to computer.

4.2. *NN Methodologies*

From the research background, it was concluded that the input data for the system consist of the parameters that can influence the lubricant quality, namely pressure, temperature and shear stress, while the output data produced by the system is the lubricant viscosity value. The outcome of the information gathered from literature reviews can be seen from the pre-processing section in Figure 3, which shows how the factors affecting the lubricant quality are arranged into a set of data starting from a lubricant condition data. Furthermore, previous observations and analysis performed on lubricants have yielded some correlations that can relate the input data with the output data.

The set of data found must be normalised to get a continuous range of viscosity values so that each can be classified according to its own viscosity value. Normalization of data is performed in this section using log values of the obtained viscosities [5].

5 NN Mathematical Model and Algorithms

Mui *et al*. [6] presents two important characteristics in NN: learning and generalization. Learning process associates with network architecture that will change the connection structure between units and signal strength in the connection structure. Generalization correlates insensitive system feedback with many kinds of input. One of the NN paradigms is known as Multi-Layer Feed Forward (MFF). MFF architecture is an extension from the single layer perceptron by Rosenblatt [17] in mid 1950's. Hagan *et al.* [7] proposes a multi-input processing model as depicted in Figure 3.

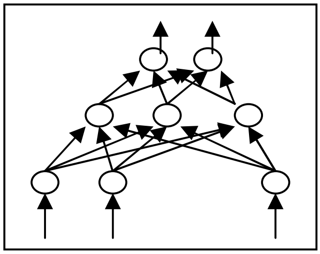

Figure 3. NN Multi-input processing.

Every input, $x_1, x_2, \ldots, x_n$ with weight $w_{1,1}, w_{1,2}, \ldots, w_{1,n}$ from weight matrix w. This neuron has bias b that will be accumulated with clean input to produce total neuron input value:

$$\text{Total Neuron Input} = \sum_{i=1}^{n} w_{1,i} x_i + b \tag{1}$$

Total neuron input value is used in the activation function *f,* and produces one scaled output neuron a which can be represented by:

$$a = f(\sum_{i=1}^{n} w_{1,i} x_i + b) \tag{2}$$

An output value depends on the activation function used. Basically there are two types of activation functions: linear and non-linear. Activation function, which is suitable with the type of problem solving and desired output range, shall be applied onto the network. According to Khairuddin [8], there are usually three kinds of activation function: Binary sigmoid, Bi-polar sigmoid, and Hiperbolic tangent.

5.1. *MFF Network*

As explained above, MFF is an extension of single layer perceptron [9]. MFF is popularly associated with backpropagation as a learning algorithm and with sigmoid function as an activation function. The architecture of MFF could be arranged according to layers and stated as below:

$$I \, x \, H \, x \, O \tag{3}$$

where are: I - numbers of node at input layer, H - numbers of node at hidden layer and O - numbers of node at output layer.

5.2. *Backpropagation (BP) Training*

BP is a downward slope method used to train weights in MFF for supervised learning. It is also known as generalized delta rules [10]. BP is a frequently used method in NN application. According to McCluskey [11], BP is the most popular algorithm and has been applied extensively.

5.3. *Weight Control*

Different initial weight is needed in delta generalization. According to Rumelhart *et al.* [12], if all weights are initialized with the same value, and if the solution needs weights that are developed with different values, the system will not learn. An effect from random weight control is a fast slope search because generated weight set is better than the other set. However, according to Refenes *et al.* [13], this situation will not give any great impact to the most optimum slope search.

Hence, this research had tested on a variety of weight control methods because this will give more speed to the system application. Three weight control methods were used: Random (R), Nguyen-Widrow (N-W) and Genetic Algorithm (GA). However, this paper will only concentrate on NW and GA Control.

5.3.1. *NW Weight Control*

This method could be used to initialize the weight value and the bias. It is said that it could focus faster than the common random weight control [4]. In this method, there will be minor adjustments to the error propagation that is based on geometrical analysis. This is performed to monitor feedbacks between neurons at hidden layer starting with one input and it will then be expanded to several input units.

Weights for layers between hidden unit and input unit are initialized with values in the range of –0.5 to 0.5, while weights for layers between hidden unit and output unit are modified so that they can enhance the capability of the learning process. Below are the variables and function used:

$$\beta = 0.7(p)^{\frac{1}{n}} \tag{4}$$

with: n - numbers of input unit, p - numbers of hidden layer, and β - scale factor.

5.3.2. *GA Weight Control*

According to Tsoi and Anderson [15], the GA method based on DNA forming process where a member of one binary series set competes to get a place in a new series set. Reunion can be accomplished by choosing two successful members in the population to be the parent generation. The new series, which is invented by splicing each main gene, will be produced to replace the old set and any unused set will be eliminated. There are four basic DNA forming processes:

1. Initialization - gives initial value to all individuals in the population.

2. Evaluation - counts fitness survival value of every individual in the population.
3. Selection - selecting new individuals with the highest fitness value.
4. Reproduction - chosen individual at the selection process will structure a new generation by using three forming techniques: cloning, crossover and mutation.

Therefore, GA also applied those four basic DNA forming processes for controlling weights. Below is a portion of GA algorithm that has been applied.

5.3.2.1. *Weight Control at GA*

An individual for this method consists of a set of weights known as a weight vector (WV). WV contains all the information needed to define a neuron, which consists of one or more inputs to the neuron and its threshold. A neuron with I input is defined to gain $(I+1)$ weights. $(I+1)$ weights will be set with a random value. This means the weight value is random and is set at a certain range. The range chosen in this research is –0.5 to 0.5 according to Fausett's [14] suggestion. Subsequently, a population with N members in WV will be formed. The number of members in a population is a parameter from GA and it could be set according to the network size (Figure 4).

Population members

	v_1	v_2	v_3	v_4	....	v_{i-1}	v_i
1	0.4568	0.3886	-0.4002	-0.1001	....	0.4563	0.2345
2	0.0008	-0.4928	-0.2110	0.2481	....	0.0023	-0.2411
3	-0.3218	0.1141	0.4565	-0.0086	....	0.3711	0.2342
				......			
				......			
N	0.3300	0.0045	0.1114	0.2168		0.1121	-0.2132

Figure 4. Weight vector population members.

Every weight is stored with fixed-point real number. Mathematically, WV could be represented as:

$$y = f\left(\sum_{i=0}^{I} w_i x_i\right) \tag{5}$$

with: y - output for neuron, I - numbers of input, x_i - input value for neuron $(i=1,2,\ldots, I)$, w_i - synaptic weights connecting input x_i with neuron $(i=1,2,\ldots, I)$, and $f(.)$ - non-linear function.

A non-linear $f(\alpha)$ is chosen:

$$f(\alpha) = \begin{cases} 0 \rightarrow \text{if } \alpha < 0 \\ 1 \rightarrow \text{if } \alpha \geq 0 \end{cases} \tag{6}$$

Generally, this process has the same process definition to one neuron on MFF. However the importance of choosing non-linear functions is that this function will help the application of GA in the network [15].

5.3.2.2. *Evaluation on GA*

Fitness evaluation is the most crucial process in GA [16] compared to other processes. Fitness evaluation (Eq. (7)) is accomplished after counting the output size of each neuron at the first hidden layer by using every pair of weight in a population. The purpose of this process is to monitor a member's fitness or capability in a population to classify output compared to other population members.

Fitness function used:

$$Fitness = \sum_{i=1}^{T} \alpha_i \tag{7}$$

where: $\alpha_i = \begin{cases} 0 & \text{if VP wrongly classify } i \text{ training vector} \\ Bias(n_i) & \text{if VP correctly classify } i \text{ training vector} \end{cases}$,

and T - sum of vector in training set, and n_i - sum of *WV* that classify training vector precisely.

Bias (n_i) is a monotonic reduction function for n_i>0. Generally, it could be selected by using this equation:

$$Bias(n_i) = \frac{1}{(n_i)^{\beta}} \tag{8}$$

with: β - numbers of non-negative integers.

A neuron will classify a training vector correctly when it matches the real output at the training vector and the bias Eq. (8) gives effective classification to the output. Fitness evaluation process for each N individual in weight population is applied continuously to every pair of training data until the sum fitness value is obtained. Only individual with the best fitness value will survive such as 1.83 and the rest are left unused such as 0.83, 0, 0.33 (Figure 5).

		1	*2*	*3*		*N*	*Correct action*
Pattern pair sets	*1*	0.5	0	0.5	....	0	2
	2	0	0	1	....	0	1
	T	0.33	0	0.33		0.33	3
Correct action		2	0	3	....	1	
Fitness		0.83	0	**1.83**		0.33	0.1121

Figure 5. Fitness Evaluation for each population members.

5.3.2.3. *Selection in GA*

Selection process is based on fitness of each member in the population. Membership with high fitness value will have a higher probability of survival than the other members. Membership probability in a population can be determined by using this function:

$$\text{Membership Probability } VP_i = \frac{r_i}{N(N+1)} \tag{9}$$

where are: VP_i - weight vector to I from current population, N - sum of population, and r_i - member's position in a population.

None of the two members in a population should have the same position. Conversely, if two populations are discovered to have the same fitness value, random selection will be carried out to get a membership with the higher position.

5.3.2.4. *Reproduction in GA*

In reproduction, there are three forming techniques to shape the new generations: cloning, crossing and mutation [15], [16], [17]. While selection between these techniques is being performed by calculating the probability for each technique desired. Though, according to De *et al.* [18], mutation could slow down the focusing process as it changes the most important byte at an individual.

Crossing and mutation will change an individual fitness value for the generation that will be formed. Yet, mutation does not have a big probability in a population [15] until attention is paid to cloning.

In the application that is being developed, crossing is accomplished by byte crossing between two individuals. A pair of parent individual will produce two members of a new generation, a male and female offspring (Figure 6).

	v_1	v_2	v_3	v_4
Chromosome	X		Y	
Father	0.4568	0.3886	-0.4002	-0.1001

Chromosome	X		Y	
Mother	0.0008	-0.4928	-0.2110	0.2481

Daughter	0.0008	-0.4928	0.4568	0.3886
Son	-0.2110	0.2481	-0.4002	-0.1001

Figure 6. Crossing Process.

Crossing the fathers' chromosomes will determine whether the new generation will produce male or female offspring.

5.4. *Application Data Structure for Data Pre-processing using Along Channel Normalization with or without Logarithm*

According to Anastasakis and Mort [19], in a preprocessing part, input vector normalization is very important. Meanwhile Robinson [20] said that normalization is significant especially when variables have different range or the value does not give any influence to output. Azoff [21] suggested many kinds of normalization such as: along, across, mixed, and external channel. In this research Along Channel normalization was applied because it allows only one normalized input without influencing another input. Below is normalization algorithm that had adapted before NN model was applied.

5.5. *Network Architecture*

According to Tsoi and Anderson [21], the network architecture can be adjusted to attain a reasonable architectural form especially to choose the total nodes at a hidden layer. There are two ways of how the total nodes at hidden layer can be applied: Firstly, if it is appropriate or enough for the network, a small number of nodes is started or else, the node number is increased. Secondly, start with a large number of nodes with assurance that they focus or diverge. Clipping or pruning any unimportant hidden nodes accomplishes this method.

Based on the explanation above, several network scheme forms will be selected and used in the testing. Scheme 3-3-1 means the network architecture is in the form of 3 input units, one hidden layer with 3 neurons and 1 output unit. Forms selected are (Table 1).

Table 1. Selected network scheme

Number of schemes	Scheme
1	3-3-1
2	3-5-1
3	3-7-1

Testing was accomplished by using a 3, 5 and 7-neuron unit hidden layer at a 10000-epoch iteration. At G control, a population with 20 and 40 individual was applied. Least error value for the NW method was found at the 10000th iteration while 291, 395 and 491 second where needed for 3 learning scheme respectively. Meanwhile, the GA method with 20 population (GA20) members needs 306, 410 and 514 seconds for each learning scheme respectively and the minimum error was detected at iteration 626, 5514 and 89 while when population members increased to 40 individuals (GA40), learning time was raised to 319, 425 and 533 seconds respectively. However, its (GA40) minimum error given had decreased from 1.5865 to 0.3620 (Table 2). From these results, the scheme 3-network learning showed that NW weight control method produced reasonable results. However the results were not enough to choose scheme 3 because the third learning performance declined, compared to the other two learning scheme. Neuron increment was not needed because it did not increase the network performance. The chosen architecture in testing was scheme 1 and scheme 3.

Table 2. Performance Comparison for 3 Kinds of Control at Scheme 1, 2, and 3 Learning.

Scheme	***Control type***	**Least Error**		**Run time (sec)**
		Error Value	***No of epoch***	
1	NW	0.30859499449758	10000	291
	GA (G20)	1.51475829851637	626	306
	GA (G40)	1.58653829233683	1443	319
2	NW	0.308580680820816	9096	395
	GA (G20)	1.90694704657125	5514	410
	GA (G40)	0.81481255966569	6406	425
3	NW	0.297888632273415	7013	491
	GA (G20)	1.49286989158451	89	514
	GA (G40)	0.362062821688018	131	533

6 Data Testing

As mentioned earlier, sample data used in the testing was divided into two parts. The first part contained 149 data and the second part contained 161 data. For the first test, the first part of the sample was used as the learning data and the second part as the testing data. At second testing, this condition was reversed (vice versa).

6.1. *Test Performance Calculation*

Test performance was based on the difference in the value between the application output and the real output. This error was compared to the real output until the percentage was gained. Error value (EV) must be calculated as logarithmic value because the output given by the application was a logarithmic value (Table 3 and 4). EPV desired was divided into two parts, EPV < = 5% and EPV < = 10%. EPV with smaller value or equal error value gives the right result (Table 3 and 4).

6.2. *First and Second Sample Data Testing*

Testing was carried out by using the first part of sample data (i.e. for 161 learning data and 149 testing data). Scheme 1 , 2 and scheme 3 were used as the network architecture. Learning rate and momentum used in the network is 0.2 and 1.0 respectively.

The best error value for testing by using the first sample data was given by Scheme 3 (3-7-1) with the NW weight control. Overall output in this testing produced satisfying result because average EPV given was below 10% (Table 3). The best EPV for the second sample data test was given by Scheme 3 (3-7-1) with the NW weight control. This test produced an EPV value above 10%, which was inadequate (Table 3) because the data pattern was too hard for the application to be identified the output logarithmic value.

The best test result using the first sample data was found at Scheme 3 (3-7-1) with the R weight control (Table 3). In this test, 69.57% generalization produced a value close to the value of the real viscosity. The GA control did not produce good generalization result because fewer individuals in the population were obtained. However, when the numbers of individuals were increased, the network required more than 10% from the overall time (Table 4).

Table 3. Output Error Percent Value (EPV) Compared to Real Output.

	EV	App. output (Log)	Actual output (Log)	*EPV* (%)	*EPV*	
					<= 5%	<= 10 %
1	0.31846	6.43965	6.75811	4.7	correct	correct
2	0.27501	6.18207	6.45708	4.3	correct	correct
3	0.27546	7.07961	7.35507	3.7	correct	correct
4	0.27894	6.77510	7.05404	4.0	correct	correct
5	0.23781	7.65689	7.89470	3.0	correct	correct
6	0.25796	7.33571	7.59367	3.4	correct	correct
7	0.24801	8.14169	8.38970	3.0	correct	correct
8	0.25580	7.83287	8.08867	3.2	correct	correct
9	0.27633	4.52529	4.24896	6.5	*incorrect*	correct
10	0.53102	4.47895	3.94793	13.5	*incorrect*	incorrect

Table 4. NN Performance and Average EPV with First and Second Sample Data

Sample data	Weight Control Type	NN Performance (%)			EPV Average (%)		
		Scheme 1	Scheme 2	Scheme 3	Scheme 1	Scheme 2	Scheme 3
First	NW	69.57	68.32	69.57	8.02	8.60	8.00
	G (20)	37.27	27.33	40.99	18.00	23.30	17.70
	G (40)	31.68	53.42	67.08	22.40	10.90	8.90
Second	NW	74.50	83.89	85.91	16.9	15.1	15.2
	G (20)	33.56	76.51	75.17	27.2	16.1	16.7
	G (40)	32.89	50.34	36.24	29.6	20.0	31.9

7 Conclusion

Based on literature reviews, there is yet any research that uses NN capability on lubricant condition monitoring. Nowadays, a lubricant condition monitoring system is required because it can reduce costs (early lubricant replacement), protect engines from damages (overdue oil replacement), and avoids hazard such as engine suddenly stops due to enlarging pistons that may be caused by the lubricant. Discussions on the research background, objectives, methodology and NN application are also mentioned in this paper. The application of NN with scheme 3-7-1 gave the best results of 85.91% accuracy in predicting the lubricant quality based on input data of temperature, pressure and sheer stress.

From the results in the implementation and testing, it is known that the most suitable NN characteristics in lubricant condition monitoring is Scheme 3 (3-7-1), because it produced the best performance either using the first or second sample data. However, it is also justified that from the test that data used was difficult to recognize by BP. But, when the output is not changed into a logarithmic value, normalization will not succeed because the range found at viscosity was too big (0 to 10^9). Along channel cannot normalize this range. Until then, modifying the output into a logarithmic value was the best decision.

Increasing the number of learning data can increase the network performance. This can be seen in the comparison between the second test result (161 pairs) and the first test (149 pairs). The second test performance leads with 16% more than the first test, even though it only has 12 pairs of additional data in its learning data.

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AIR QUALITY CONTROL IN BOR

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This paper briefly describes renewed part of the system for air quality monitoring in Bor. Some specific details of hardware and software installation where specially noted. Second part of paper shows gathered experiences during system usage, with presentation of different types of reports for public.

1 Introduction

Bor is industrial town situated at southeast of Republic of Serbia. Town area, with population of more than 50000 inhabitants, is in constant influence of air pollution as a consequence of technological processes in Copper Smelting Plant. In Copper Institute, Department for Chemical and Technical Control, more than 20 years exists section for measuring of meteo parameters and air quality control. Most of the systems for air quality monitoring in Western European countries work on real time bases. Present state of air quality control in almost all industrial centres in SCG based on taking samples one or few times per day, which means that there is no information about time distribution of polluted materials intensity during day. That is the main failure of such control, having in mind often changes of meteo conditions. To prevent air pollution we have to provide real time monitoring of all polluted materials at proper locations by using distributed monitoring system on real time bases. For the aim of better measuring efficiency, engineers from Copper Institute, Department for Industrial Informatics, developed, produced and put into operation automatic measuring station [1]. That station has been working 24 hours per day since 1997. On the bases of positive experience in work with automatic station we have unsuccessfully tried to enlarge and expand air quality monitoring system. We insisted on system enlargement with equipment for waste gas

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concentration monitoring (first of all for SO_2). For that purpose all required projects were created [2]. Finally, by UNEP (United Nations Environment Protection) donation, two fixed stations for SO_2 monitoring (Environnement SA), mobile station for dust concentration monitoring (PM10), and dust sampler for heavy metal concentration analyses have arrived in Bor during summer 2003.

2 Choosing locations for fixed stations

One the bases of meteorological data which has been collected for more then 20 years proper locations for taking samples was established. Those locations are chosen after air pollution imission modelling [3]. The most important parameters that have to be taken in account for air pollution imission modelling are of course: wind speed, wind direction, pressure, temperature gradient and topography. Table 1 shows average values of temperature, humidity and pressure in Bor town area. Table 2 shows average values of wind appearance and wind speed. Figure 1 shows wind rose created from data given in Table 2.

Table 1. Average values of temperature, humidity and pressure in Bor (1984- 2004).

Month/ parameter	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
t^0 C	-0.7	1.8	6.5	11.4	16.2	19.2	22.2	22.6	16.4	11.4	4.6	0.8
Humidity %	82	74	68	67	67	63	62	57	70	78	85	77
P mbar	974	971	971	969	969	972	970	972	969	977	974	974

Table 2. Average values of wind appearance and wind speed in Bor (1984- 2004).

	N	NNE	NE	ENE	E	ESE	SE	SSE
%	1.0	0.4	0.4	4.6	4.2	0.7	0.3	0.2
m/s	1.5	1.7	1.8	1.6	1.6	0.8	0.9	1.0
	S	SSW	SW	WSW	W	WNW	NW	NNW
%	2.7	0.6	0.3	0.7	4.8	6.8	9.8	1.3
m/s	1.5	1.2	1.1	1.2	1.8	2.3	2.4	1.8

One fixed station for SO_2 concentration monitoring was situated in Town Park, other at Jugopetrol warehouse (see Figure 2). The station in Town Park is equipped with meteo sensors. Meteorological parameters are also measured at Copper Institute by automatic fixed station. Figure 1 also shows suitable locations for mobile station. Measuring concentrations of flying particles (dust monitoring), at those locations, happens occasionally, which depends on wind direction and other meteo conditions.

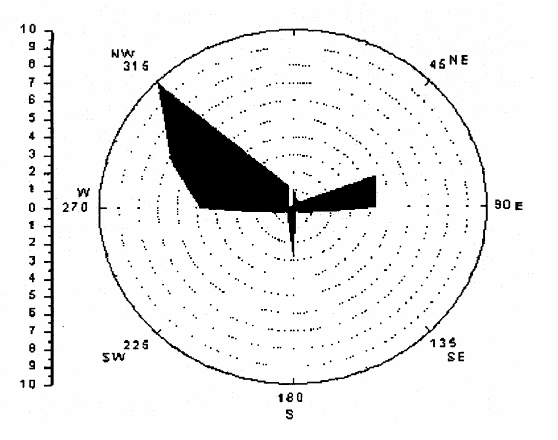

Figure 1. Wind rose (based on data from Table 2).

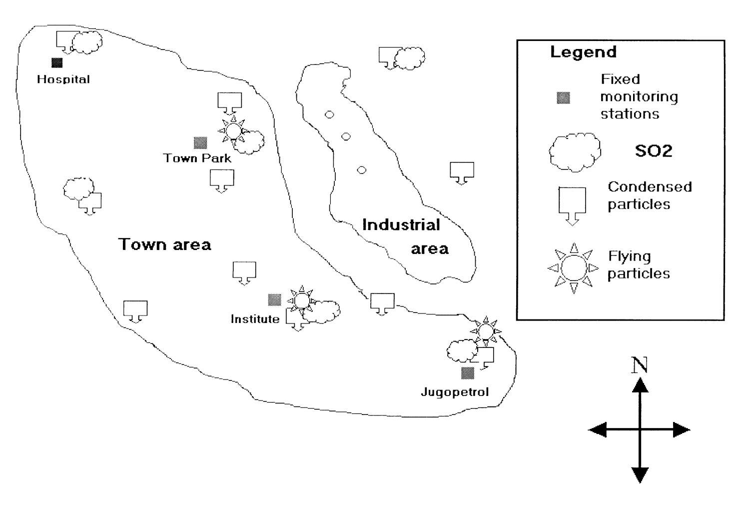

Figure 2. Locations for taking samples and placing measuring stations.

3 Fixed stations

Measuring stations for SO_2 monitoring are microprocessor-controlled devices with local displays and function keyboards. Every station has auto calibration function, and possibility for local or remote user define adjustment of measuring parameters, average, and storage intervals, as well as diagnostic and auto calibration. As communication interface each station has RS 232 ports. Stations are situated in proper air-conditioned container, equipped with unbreakable power supply (UPS).

Classical switched telephone lines are used for communications between fixed stations for SO_2 monitoring and PC (which is situated at control centre in Copper Institute). There is one asynchronous modem per each station. On the PC in control centre (Windows XP) has been installed program *Contact* for interactive work with fixed stations. By the aid of this program, after establishing connection, one may attach and use all set of function on remote place like it does locally. On the same PC has been installed program *WinLoad* for data transfer of measuring results from fixed stations. Measuring results being stored in text files (one file per station). The Copper Institute's fixed automatic meteo/eco station is also a part of new monitoring system. As we noted this station has own PC in control centre since 1997. Now it's connected in local area network (LAN) with PC for SO_2 monitoring. Figure 3 shows new configuration of real time air quality monitoring system.

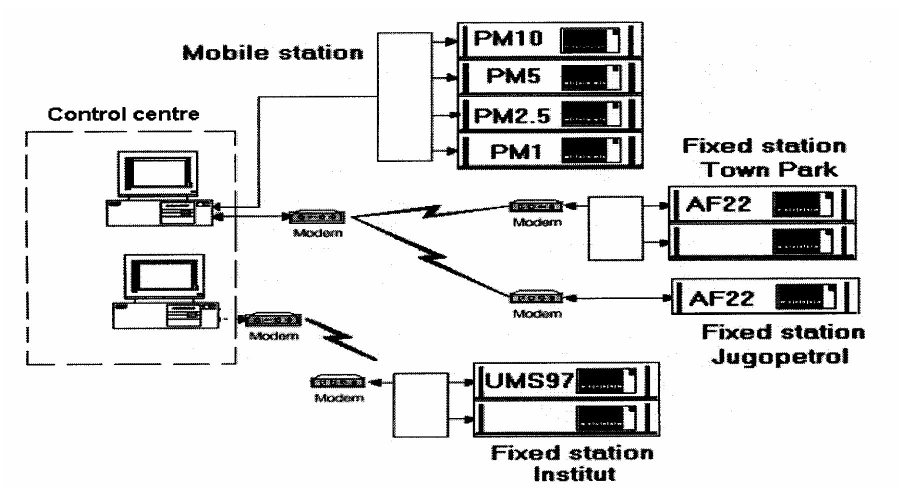

Figure 3. New configuration of air quality monitoring system.

4 Mobile station

Mobile station (made by Turnkey Instruments Ltd.) are able for continuous, simultaneous, on site measurement of TSP, PM10 and PM 1. Downloading results from mobile stations to PC is controlled by program *AirQ32*. That program, beside data transfer options, provides other useful tools for graphical presentations, exporting data and creating reports. In case of no AC power source on site, station has own DC battery for several hours' continuous work.

5 Way of operation

Data transfer from fixed stations to PC occurs periodically, fully programmed and controlled by PC. Mobile station uses (periodically) direct connection with PC for data downloading. For the real time monitoring of air quality some special tasks were created (for data transferring, extracting and importing into Excel worksheets) which runs on every xx minutes. Graphic data presentation occurs with control of Visual Basic modules in Excel, so new data values appears in worksheets, and charts on every xx minutes.

Figure 4 shows one example of chart with SO_2 concentration provide by monitoring system.

6 Presentation of measuring results

On the bases of long-term experiences in air quality control, and often consultations with UNEP experts, the way of operation, forms and contents of reports were established. It was agreed that average values from fixed stations has to be transferred to PC (situated at control centre in Copper Institute) on every 15 minutes. Copper Institute monitoring team, besides of creating appropriate program solutions, has an obligation to define, organize and maximally simplify all system operating procedures. Real time air monitoring program on PC include data comparison with limit values, visual and sound alarms.

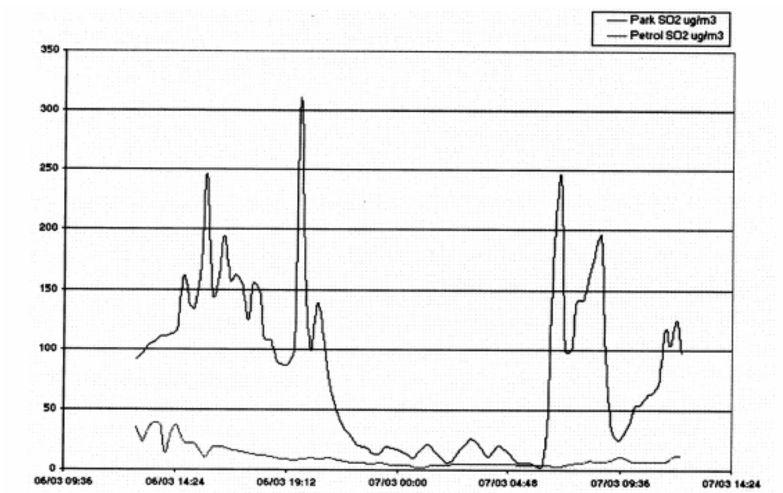

Figure 4. An example of chart with SO_2 concentrations provide by monitoring system.

As well as, almost all procedures for off-line reporting (weekly, monthly, quarterly or annually) were completely automated. Those reports are for public use by the means of local media (TV, radio or news boards). Weekly and monthly reports consists of tables with statistical presentations of air quality on each measure point, ‘rose of winds’ for time interval of concern, as well as graphic comparison of production of SO_2 in RTB Bor plants, and concentrations of those gas at measure points in town (Figures 5, 6).

7 Conclusion

In the process of installation, testing and system calibration there was a lot of troubles. Quite unexpected, organization problems was much stronger than technical. After few months of experimental work, monitoring system was put into operation. Until this days system has shown good stability and repeatability. Comparisons of system results (Table 3) with others obtained by classical methods shows good agreement.

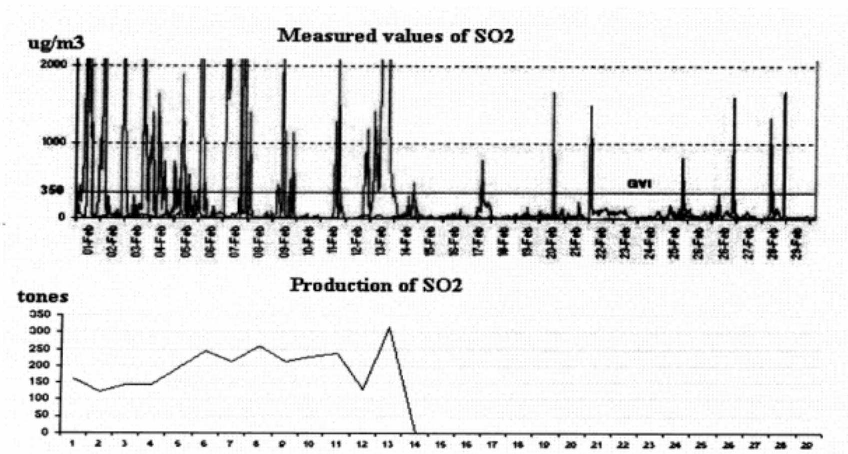

Figure 5. Part of monthly report with graphic presentations of production and measured values of SO_2 in town.

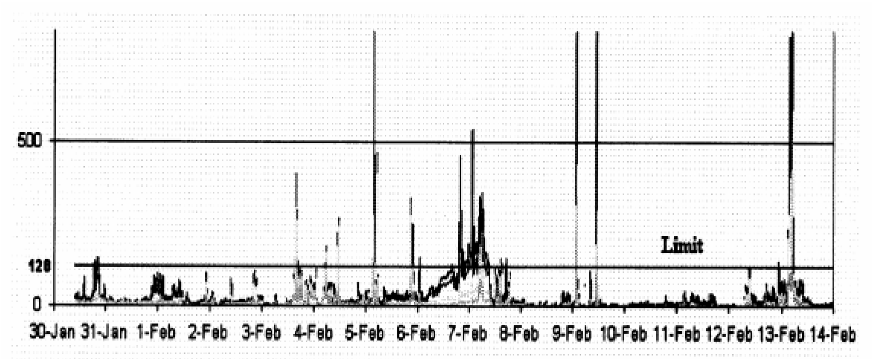

Figure 6. Part of monthly report with graphic presentations of flying particles (PM10).

Table 3. Part of monthly report with tabular presentation of heavy metal concentrations.

Measuring Point	Pb µg/m3	Cu µg/m3	Ni ng/m3	As ng/m3	Cd µg/m3	Hg µg/m3
Jugopetrol 30.01-17.02.04.	0,25	1,6	47,1	159	0,006	0,007
NGC 19.02-25.02.04.	0,09	2,4	0	51,6	0,005	0,04
Institut 26.02-29.02.04.	0,07	1,1	0	53,5	0,001	0,04
Limit (GVI)	1	-	2,5	2,5	0,010	1

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