Hidefumi Imura

Environmental Systems Studies

A Macroscope for Understanding and Operating Spaceship Earth

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KANKYO MONDAI WO SHISUTEMU TEKI NI KANGAERU

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Preface

As environmental problems become increasingly important today, we already see many undergraduate and graduate schools featuring their own educational or research programs related to the environment. At the same time, many academic fields have become associated with environmental sciences and studies, although no broad consensus actually exists yet about a systematic structure to connect those fields. In many cases it seems that groups of individuals or academic societies would like to see that system of scholarship focused mainly on their own areas of specialization. Having been affiliated with a number of academic societies, I have noticed that the types of people involved differ with each society, and even when considering a similar topic, their ways of thinking are quite different. I am constantly amazed at how diverse the approaches can be for people of different backgrounds, even among colleagues who specialize in the same environmental problem.

If we define the field of medicine as one that heals or prevents illness by explaining the physiological mechanisms of the human body, then environmental studies could be considered the field of medicine for the Earth. It makes extensive use of the knowledge of science and is a field of study with the practical objectives and applications of ensuring the continued well-being and survival of humanity. Environmental studies must grow into a field of study that investigates how to protect the life and health of the living body known as the Earth by bringing together, in an interdisciplinary manner, knowledge from other established academic fields. Just as many items are included in a health checkup for the human body, a variety of indicators have been developed to determine the health of the global environment. We must further develop such indicators, use them to monitor the health of the Earth, and then apply the findings to prevent and treat the ills.

The environmental field is deep and wide. When we get into the specifics of individual phenomena, even the experts cannot agree among themselves. I have been fortunate to have had many opportunities to learn from numerous experts, however, and through this experience, I have searched in my own way to find common methods of analysis and thinking to approach environmental problems as "environmental systems studies" by looking at problems from an overarching perspective, identifying their core essence, and considering the conceptual structures needed to come up with countermeasures. For quite some time I have wished to compile this material into one volume as a service to anyone who might want to approach environmental problems methodically from these foundations—whether they are students or are already working professionals, and regardless of background, whether it be the sciences, the humanities, or any other discipline.

One of the challenges in environmental systems studies, for both instructors and students, is the dearth of suitable textbooks. There are many good compilations on specific subjects, but it is difficult to find any one source that students can use to learn about the various dimensions of environmental issues in just one volume. The aim of this book is to cover the many key points required to understand the key issues in a way that offers knowledge in economics and other areas in the humanities to persons specialized in the sciences, and conversely, that provides information related to sciences—such as climate change and resource circulation—to persons specialized in the humanities. Indeed, this is exactly what I wish to achieve with a systems approach to understanding environmental problems. With this publication, it is my hope that readers will be able to "connect the dots" of knowledge in their minds, so that those dots can reveal themselves as lines, and the lines can combine to become planes and networks. This is a challenge to bring together knowledge from various academic fields and investigate how to protect the health of the Earth.

Motivated by these thoughts mentioned above, I wrote the Japanese version of this book in 2008. Subsequently, I wished to publish the same material in English for a much wider audience. It took considerably longer than I planned, however, for many reasons. It was not a simple translation from Japanese to English, but it was also a challenge to rethink the issues from the ground up. It was something like transplanting Japanese trees in a foreign land, and for doing this work I am very grateful to Mr. Randal Helten and Ms Kazuko Watanabe for their valuable advice and suggestions.

Yokohama, Japan Hidefumi Imura

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Chapter 1
Seeing and Understanding Connections Between Nature and Humanity

1.1 Introduction: How to Address Environmental Problems

Nowadays, the amount of information available about environmental issues is growing dramatically. But are we drowning in this sea of information? Confronted by this flood of information, we tend to believe what we see in the media or hear from people around us and to be indifferent to anything not reported in the media. As a result, people may have a tendency to simply accept whatever is reported, instead of digging deeper to understand the underlying causes of what they hear stated. Thus, without realizing it, it is as if this information has us under a state of mind control. This state is both a feature and a hazard of living in our modern information-based society. What, then, is the best way to understand environmental issues? Above all, it is important that we make our best effort to understand the issues correctly from a scientific basis. Actually, however, this is not as easy as one might think. In fact, one might say it is almost impossible. There are many issues on which leading scientists in a certain field cannot agree about the scientific conclusions even among themselves.

Environmental issues are connected with human values and thought. Indeed, it is humans who are the perpetrators of environmental problems. To address these problems, it is humanity that must do something, but any action is likely to incur costs, and any time someone attempts to change the status quo, there will be resistance from someone whose interests differ. Whatever the human activity, there will almost certainly be some form of environmental impact, and those impacts create both victims and beneficiaries. Furthermore, the extent of positives and negatives will vary—by country, by region, by person, and so on. Inevitably, there will also be differences in the level of understanding and perception of problems, making it difficult to achieve a common perception and consensus.

We use the environment as a resource, and in some cases we damage it. We also enjoy economic benefits from the use of the environment. One could say there is a trade-off relationship between the environment and the economy. If the scale of the problem is large, however, the situation actually reverses. Global warming is one such example. If the world's average temperature increases by more than 3°C—for

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example, by 5°—the impacts could be enormous. Even though certain regions may benefit, on the whole the negative impacts would be overwhelming. This scenario would unfold in the future—and humans tend to give greater weight to real rewards today than to undetermined future losses. So, there will always be someone of the opinion that urgent action is not needed, making it hard to reach consensus or a common understanding—whether it be in relationship to the scientific analysis of the actual phenomena or about the actions that society must take.

In the face of challenges such as these, what is the best way for a person to cope objectively with the variety of information available and form one's own opinions and stances? Environmental problems are indeed "problems" because they demand solutions. It is not enough to simply think of them as phenomena to be analyzed. It is also necessary to grasp the nature and urgency of the problem, to propose suitable solutions, and to implement the solutions. The role of technology to that end is important, but technologies used to handle the problem may also spawn new problems of their own. This consequence is similar to fighting a disease with a miracle cure that turns out to have devastating side effects. Furthermore, it is not enough to simply use technology to solve a problem. It is also necessary to have control through legislation, as well as economic incentives, education, and, amongst others, firm political will and social consensus to take actions to protect the environment.

1.2 Relationship Between Nature and Humans

One feature of environmental problems is their breadth. The problems are diverse, and many of them cannot be properly understood without a background in the natural sciences, engineering, economics, and a variety of other disciplines. Not only are they broad, each separate problem is also very deep. Meanwhile, if we become too narrowly focused on one problem, our thinking becomes partitioned and we may fail to "see the forest for the trees." When choosing a map, if you know your destination well, it is fine to use a close-up, detailed map of the neighborhood to begin with, but if you are visiting for the first time, it would be best to use the local map only after looking at the large-scale map of the city. Environmental problems are also like this. They require a combination of both a macro-level understanding of the overarching aspects and a micro-level understanding of the details. If we look objectively at the status of our knowledge today we are likely to get the impression that humanity has accumulated a vast amount of knowledge about micro-aspects, and that experts are plentiful, but we may still be weak when it comes to looking at problems at the macro level and prescribing effective solutions.

This book tries to see "environmental systems" as the synergistic relationships created by interactions between nature and humans. It aims at developing a framework of "environmental systems studies" that analyzes those relationships systematically. These efforts are still a work in progress, but the author strongly believes in the importance of an approach that tackles these phases as systems—an approach that looks at environmental problems in terms of their causes, mechanisms, response technologies, socioeconomic aspects, and institutions.

The starting point to think about this is the relationship between environmental space and human activity at both local and global levels. In the process, we come upon the fundamental issues of how large a human population and how much economic activity can be supported under the qualitative and quantitative constraints on the resources available in a given region. It is necessary to understand global-level climate and meteorological systems—particularly relating to energy, atmospheric, and water cycles—and to think about what constraints are placed on human economic activity by the resource base, that is, the land, water, forests, biodiversity, food, fossil fuels, mineral resources, and so on, and about the systems and technologies needed to overcome those constraints.

To read this book is also a challenge for the reader to bring together knowledge from various academic fields and investigate how to protect the health of the Earth.

1.3 Perceiving That Which Is Not Obvious

Behold a picture of a face. If you use a magnifying glass, it will appear merely as a collection of dots. If you reduce the magnification, however, at a certain point it will begin to look like a face again. Sometimes, if you try this same type of process on information that at first glance appears to be random and devoid of any particular meaning, significant information will reveal itself. The term "emergence" captures the concept of this kind of phenomenon [1, 2].

If you look at the Milky Way in the night sky using a telescope with a suitable magnification, you will see a collection of countless stars. The magnification must be just right: too low, and you can see the galaxy but not that it contains many stars; too high, and you can see individual stars, but not the features of the galaxy.

We who live upon the Earth cannot see the whole planet, but seen from a satellite orbiting above it appears clearly as something floating in space—truly a spaceship. The ancient figures and lines drawn in the Naska Desert of Peru similarly only reveal their true shapes when viewed from the sky above. Small things, too, reveal themselves when seen through the lens of a microscope. One frame of a movie film is nothing but a snapshot, but if you run a series of images through a projector, the change over time recreates a story.

1.4 Understanding Environmental Systems: How Should We See Complex Issues?

To understand the relationships between nature and humanity, it is necessary to analyze the many elements that make them up as well as their interrelationships. Returning to our metaphor, if we use a microscope with the proper magnification, we can enlarge and see the interrelationships between humanity and nature that cannot be seen with the naked eye, and conversely, by telescope we can better understand the overall phenomenon. By viewing a series of still photos in rapid succession, we can compress and see long-term changes, and conversely, if we view them slowly, we can view rapid changes stretched out over time.

The common thread here is that rather than just taking the available information at face value, we must be selective and discover the interconnections between bits of information. By this effort we discover what is most meaningful. A good example is when we take the data from a scientific experiment and convert it into a line graph or bar graph: the numbers cease to be just numbers and reveal meaningful information.

Even if you discover order by looking at figures and graphs, however, this step alone will not solve problems. We must also discover the principles functioning behind this order. This imperative could even be considered as a basic principle of environmental systems studies. Referring to this as a basic principle may make it sound difficult, but it is sufficient to think of this as a pillar of theoretical thought—a guide for thinking.

Specialists have a tendency to inject jargon into their communications, which may intimidate nonspecialists. The environmental fields are no exception. People who make themselves familiar with the knowledge and concepts that frequently arise when debating issues in a certain field will find themselves having a marked improvement in their understanding of those issues. Such knowledge will also give them a growing capacity to decipher and interpret the data.

1.5 The Role of Environmental Systems Analysis: Making the Invisible Visible

This book advocates "environmental systems studies" as a system of scholarship to methodically analyze a variety of environmental issues and phenomena. It is within a field relating to the environment—environmental studies—and puts an emphasis particularly on the systems approach.

Even in today's world, despite tremendous scientific progress, an overwhelming number of complex natural phenomena have not yet been fully explained. Human activities—consisting of socioeconomic systems—are interconnected in complex ways and are further complicated by the complexity of individual and group interests, desires, and values. The intricate connections between nature and humans involve many factors, consisting of complex systems tied together through feedback loops.

The term complex systems used here refers to more than just the literal meaning of systems that are complex. In recent years a field of research into complex systems has emerged to examine the common features of such systems [3–8].

One characteristic of complex systems is the special correlations that arise between inputs and outputs. For example, certain values for input variables will produce extreme outputs, such as phenomena known as catastrophe and chaos [9]. The game of Othello is one such example. The interesting thing about the game is that one player's turn can suddenly reverse his or her position. It is a simple system but can behave in a complex way. Actually, the concept of "emergence" mentioned earlier also arose from research into complex systems.

A major role of environmental systems studies is to make the invisible visible or make the complex easier to see, by unraveling complex problems. The first step starts with clarifying the connections among the various elements that connect humanity and nature and understanding the characteristics of systems as the sum of interrelationships. Here it is important to be careful about the degree of detail when analyzing the elements. As we saw in the foregoing example about a photograph of a face, if it is too detailed, we will only see the collection of dots. It is therefore essential to choose the appropriate level of magnification to see the features of the human face. In other words, depending on the subject of analysis, it is essential to use the proper time scale and spatial scale, and with human groupings as well, it is essential to decide on which level to examine, be it the world, the country, the municipality, or the individual.

To analyze a complex system, it is not always best to obtain the most elements possible. The larger phenomena we see, whether natural or socioeconomic, are macro-level phenomena, but they cannot be recreated at the macro level simply as the summation of micro-elements. This limitation can be understood from the fact that modern economics consists of macroeconomics, which deals with the performance of the whole economy of nations, regions, and the world, and microeconomics, which studies the behavior of individual households and firms. Similarly, physics is made up of thermodynamics, which delineates the macroscopic bulk properties of materials and statistical mechanics that provides a molecular-level interpretation of macroscopic thermodynamics.

The Earth's climate system—the circulation of air and water driven by solar energy—could also be considered as a type of complex system that is the subject of environmental studies [10]. Other examples of complex systems are the ecosystems created through interactions among living things, which continue to evolve in response to this climate system [11, 12]. The business cycles created by human economic activities provide other examples [13].

To analyze such systems, we must have both a macro- understanding of large-scale behavior and a micro- analysis of detailed system constituents. Depending on the nature of the problem, a middle approach may also be required that focuses attention on the subsystems which constitute the systems. Ecosystems consist of a large number of diverse species, and although we may view them broadly as individual systems, it is also necessary to look at ecosystems at the level of each species and the individuals within them and, in fact, even at the cellular and genetic levels.

The subjects of environmental systems analysis also include many problems that cannot be explained by numbers alone. Good examples of this point include the urban amenities, the visual attractiveness of landscapes and livability of neighborhoods. Another point to note is that even if one understood the relationships between humanity and nature, this would not automatically make decision making happen. The question of what priority to give the environment when comprehensively evaluating the advantages and disadvantages of various factors and making policy decisions depends on how the various players in society—individual citizens, corporations, and so on—value the environment. One other important function of environmental systems studies is to continue providing comprehensible and accurate information on the environment that can help with the consensus building and decisionmaking of our society.

1.6 Nature and Humanity: Understanding the Connections

For detailed analyses of environmental problems, it is important to have an understanding of both natural phenomena and the socioeconomic activities that affect them. Research into specific natural phenomena falls under existing academic fields that specialize in such areas as meteorology, biology, ecology, atmospheric chemistry, and oceanography. An important function of environmental systems analysis is to utilize the findings of these disciplines to analyze the impacts of human activities on the environment and, conversely, to examine the effects of those impacts on humans. A detailed understanding of human activities—in other words, socioeconomic analysis—is another important pillar of such efforts.

Consider global warming, for example. What amount of greenhouse gases would be emitted if current technologies were applied for the next 50 or 100 years and if economic growth in each country continues according to a certain scenario? What would be the impact on global warming? Or, if we shift to other technology systems, how would the outcomes change, and how would the outcomes affect the world? These are key themes to be addressed.

Many similar problems exist for individual river systems, lakes, seas, and so on. For example, key themes for Lake Biwa in Japan would relate to pollution from development around the lake. How polluted is the lake? What are the causes? And what methods are available to clean it up? The systems under consideration consist of many constituent factors. It is important to conduct research on the relevant factors, which have many detailed components. Without that research, it would be difficult to understand the entire system. An adequate understanding of those components is a precondition, but the special role of environmental systems studies is to help us understand the systems that are created by the interconnection between nature and human society.

Figure 1.1 shows the concept of environmental systems studies and their role in environmental management.

1.7 Facilitating Rational Decision-Making

The foregoing discussion about environmental studies and environmental systems studies is based on the implicit assumption that human judgment and decision making are rational and reasonable. Humans are, however, often described as "Homo economicus" [14]. They are rational and narrowly self-interested actors. In the face of their own desires, they can easily ignore long-term and uncertain information. Special consideration is needed to prepare and present

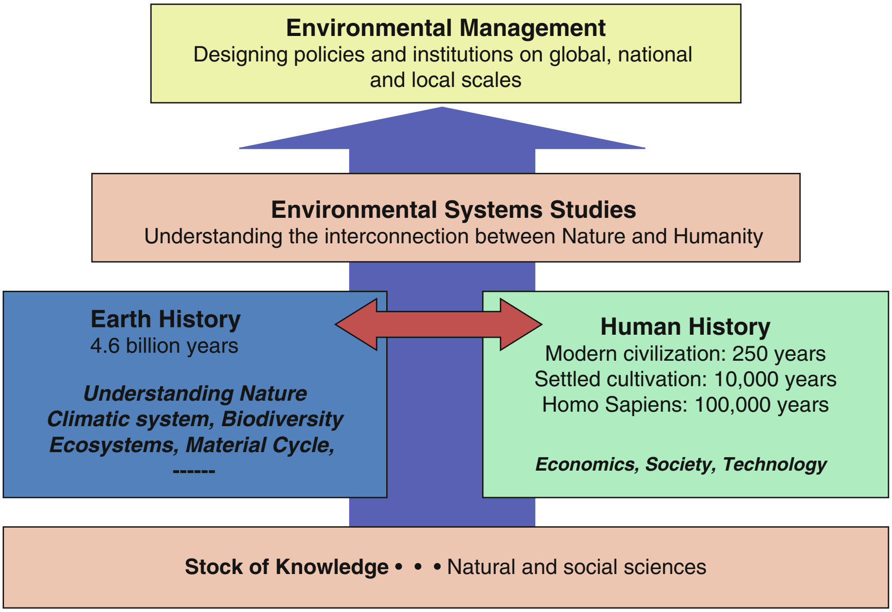

Fig. 1.1 The concept of environmental systems studies and their role in environmental management

information in ways that can cause changes in human behavior. To examine one such attempt, let us consider the activities of the Intergovernmental Panel on Climate Change (IPCC).

The IPCC was established in 1988 to synthesize available human knowledge about global warming. It consists of a few thousand scientists and policy officials from countries around the world who investigate and discuss these topics. The IPCC conducts analyses and assessments to address various questions. For example, is global warming really occurring [10]? What might be its impacts [15]? How much might future temperatures and sea levels rise if current world population growth and economic growth continue? And, what would be the effects of various technological and economic countermeasures [16]?

Regarding countermeasures, the IPCC considers a wide spectrum of possibilities for future predictions and conducts analysis using different scenarios. These detailed analyses are based on a mountain of literature from around the world. The IPCC also summarizes the essence of its findings into easy-to-understand and condensed formats, so that policymakers and others can understand the key findings [17]. This work is a labor of making it easier to see that which had been difficult to see.

Although environmental studies often focus at the regional level, the important thing at every level is that they clarify environmental changes that may have escaped notice even though they occur right before our eyes. Such studies provide information about what these changes mean to local human activities, to human society and economy; what conditions should be sustained locally; and to that end, what kinds of measures or methods might be undertaken. Through this work, environmental systems studies contribute to rational decision making. This kind of information also helps improve citizens' and corporations' understanding of environmental problems, which leads to local consensus building and to the implementation of effective measures based on that consensus.

In every discipline, the pure pursuit of knowledge is obviously a good thing. This fundamental scholarship also exists in environmental systems studies, which in many cases do not necessarily seek practical applications. Certain themes—for example, What is the value of nature for humanity? How can attitudes favorable to the environment be formed? What are the different views held in human societies about environmental problems and how should those differences be resolved? etc.—are ultimately about the relationships between nature and humanity, although it is true that they can also contribute to environmental management.

1.8 Policy Decisions on Development and Conservation

The human act of using nature is often referred to as development [18, 19]. Human activity consists of a countless number of acts of "development," and the issue of environmental protection could be seen as relating to one's assessment of the environmental impacts brought about by those acts. This issue also relates to conflicts between two typical stances on the relationship between nature and humanity: whether to prioritize development or to prioritize the environment. One stance seeks, to the greatest extent possible, to eliminate the interference of humans in nature. The other accepts the idea that humanity can actively exploit nature for its own benefit. These are also the differences between "ecocentrism" and "anthropocentrism," as described later in Chap. 7 [20, 21].

If we were to accept one extreme, there would be no need for environmental studies. Just like other animals, humans could live as a part of nature and simply accept the destiny that nature gives us. If we were to accept the other extreme, humans could completely ignore nature, and again there would be no need for environmental studies. For humanity to live on Earth, we need to have harmony with the environment, but our hand on the environment must not be too careless; often we must act to control our desires, and it is here that the need and the role exist for scholarship specializing in environmental issues.

Human cleverness and technology have given us the ability to predict, to some extent, the impacts we have on nature, and we also have the ability, to some extent, to avoid the negative impacts that return from nature to us. We would be wise to use those abilities to moderate our own activities. Others may have different thoughts on this point, but the author personally believes that by improving our understanding of the connection between humanity and nature, we can realize a more positive relationship with nature.

We must also recognize, however, that humanity is not omnipotent when it comes to controlling and managing the environment. In fact, our powers are extremely limited. Furthermore, even if we were able to accurately predict our impacts on the environment, it is not entirely self-evident what actions we should take. The choice to engage in a behavior that will affect the environment is taken because it is expected to have some kind of benefit for society, or at least for certain people in society; thus, it is difficult to obtain complete consensus of all members of society when it comes to stopping or preventing this behavior. So there is the challenge. If we weigh the merits of development against the demerits of negative impacts on the environment, what will be the correct judgment?

Recently, advances in environmental economics have produced research methodologies to carry out cost–benefit analyses and quantify both the positives and negatives of development in monetary terms. Numbers cannot solve everything, however. Certain values cannot be represented quantitatively, and these values differ with each person, culture, and era. Also, such approaches run the serious risk of trying pass judgment on the big picture based only on selected information extracted from the whole.

1.9 Macro and Micro: Grand Views and Detailed Analysis

Environmental studies themselves are a system of scholarship that aims to help us to understand the connection between humanity and nature, and to create a positive relationship between the two. To that end, it is necessary to recognize and understand the mutual relationships between nature and humanity, by using a variety of techniques and methodologies; environmental studies are structured as a collection of the knowledge required for that purpose. Both macro- and micro-approaches are necessary in environmental studies: these could be called macro-environmental studies and micro-environmental studies.

Macro-environmental studies take the broad perspective of the relationships between human activities and the environment at the level of the entire globe, continents, countries, cities, and watersheds. This system of scholarship analyzes environmental space—in other words, the environmental constraints on human activities, and the potential scope of human activities within those constraints.

Medicine as a field deals with human health and illness, and it includes both basic and clinical medicine. Similarly, environmental studies deal with the health and ills of the Earth, and we could say this field includes both basic environmental studies and clinical environmental studies. The environmental systems studies that the author wishes to discuss here are based on the search to bridge basic and clinical environmental studies with an aim to examining the relationships between nature and humanity and to improve human activities and decision making. They are rooted more in the macro rather than the micro-domain. We must never forget, however, that this macro area of study is possible only because of the accumulation of vast amounts of knowledge and new discoveries in the micro-domain.

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Chapter 2
Operating Our Spaceship Earth

2.1 The Earth and Humanity

2.1.1 Spaceship Earth

The Earth is a planet floating in space. Its size is finite, as are the resources present here. So long as the sun continues to burn during its long life, however, the Earth will continue to receive solar energy. With the exception of meteors and the like from space, solar energy is the only resource that can be obtained from beyond the Earth in any sustained manner. Solar energy, therefore, is the key factor that can really ensure sustainability on Earth.

The drive to exceed the limits of our finite resources—in response to the need for more land and food, for example—has fostered human intelligence. Human prosperity today is the result. Human creativity, science and technology should rightly be dedicated to overcoming the limits we face, and indeed, those are the real drivers of progress and development. Short of moving to another planet, however, there is no other way that we can overcome the physical and quantitative limits that are determined by the size of this planet known as the Earth.

The concepts of the Earth as a spaceship, and of "Spaceship Earth," clearly adopt this line of thought. This term was first used by architect and thinker R. Buckminster Fuller in his book *Operating Manual for Spaceship Earth* (1963), and it was further popularized by a 1966 paper written by economist Kenneth E. Boulding titled "The Economics of the Coming Spaceship Earth" [1, 2].

Fuller, Boulding, and other thinkers tell us clearly that the Earth's resources are finite and that it is impossible to sustain an "open economy" based on the presumption of unlimited resources. Fuller points out that it is solar energy that the Earth can continuously receive from outside and tells us the folly of continuing to consume the finite fossil fuels that have accumulated over the long history of the Earth. Boulding referred to a "cowboy economy" as a wasteful one that ignores the finiteness of resources and wrote that in the future a "closed economy" must keep economic activity within a cyclical global ecological system. This is nothing less

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than today's concept of the "circular economy" [3]. The global population in the 1960s when those works were published was still under four billion. Today it is over seven billion. The ideas they proposed are increasingly relevant today.

2.1.2 A Shrinking Planet

The cause of environmental problems could be attributed to the rapid increase in resource and energy consumption associated with population and economic growth. For humanity, the world is quickly becoming a smaller place, and we are like a fish whose body has grown too big for its fish tank. The air and food in the tank have begun to run out, and the water is becoming polluted from excretion. That the Earth was a body floating in space has been known since ancient Greece. Even so, for a long time after that, much of the Earth was an enormous unknown domain. The first time the author felt the smallness of the Earth was when he traveled from Japan to Brazil on the opposite side of the Earth. The flight from Tokyo via New York to Sao Paolo took 24 h. Although this was a great distance, this experience drove home the point that anyone could circle the entire globe by flying for merely 48 h.

In 1969, man first stood on the face of the moon during the United States' Apollo 11 space mission. The Earth seen from the moon is four times larger than the moon seen from the Earth, and it sparkles blue (Fig. 2.1). Our planet is the Spaceship Earth that carries seven billion people and many other living things. Our challenge is learning how to operate it. Apollo 11 succeeded despite a number of technical problems. Failure of a small component or a small system error could have resulted in a serious accident. In a way, environmental problems are similar to breakdowns and system errors on our spaceship. We must come to realize that a small failure could lead to the ruin of Spaceship Earth.

2.1.3 Humanity and Environment: Interconnected

Environment could be seen as nothing less than the entire Earth that humanity lives on: it is everything that flourishes around us, thanks to the interactions of solar energy, atmosphere, water, soil, and all living things. Humans are living things that live by taking resources from the natural world and using the environment. What is different between humans and other living things is that humans are the only animals with the capacity to control and manage their environment according to our will through the advanced knowledge that we possess and the technologies born from that knowledge.

Controlling and managing nature is a very difficult thing, however. Nature also has the destructive power we can see in typhoons, hurricanes, storms, floods, earthquakes, volcanic eruptions, and tsunamis. Humans do not have the power to

Fig. 2.1 Planet earth as seen from the moon

directly prevent the occurrence of these extreme events, but by predicting the path of typhoons, hurricanes, and storms, and by building breakwaters to hold back floods, we do have the capacity to reduce the damage they cause. Meanwhile, as a result of the expansion of the size and extent of human activities, large changes are occurring in nature itself.

Until now the condition of the global environment has changed in accordance with the rhythms of nature—the rules of evolution of the universe—but those rhythms are changing as a result of human activities. Global warming has become a matter of serious concern for all of humanity today, although in the past 4.6 billion years of the Earth's history there were periods much hotter and much colder than today. The phenomenon of climate change itself as a process of nature is neither right nor wrong, neither good nor bad [4–6].

The problem is that the rhythms of nature have been disrupted by human activities, and those changes are having enormous impacts not only on humanity, but on all things living on Earth. The most serious among these impacts is the extinction of species. Already in the past there have been innumerable species extinctions and new appearances through the processes of evolution of life, so extinction in itself is not a extraordinary event. The problem is that we humans are causing environmental changes that exceed the capacity of species to adapt and evolve in response to changes [7–9].

2.1.4 Recognizing and Understanding the Finiteness of the Earth

Since the dawn of history, or at least since the beginning of agriculture and the creation of human settlements, the human population has continued to grow and the human consumption of resources has climbed steadily. It is almost self-evident that our consumption of resources cannot possibly continue to increase forever. We must therefore ask ourselves this: What is the *optimum* human population on the Earth? And how many humans *can* live on Earth? The first factor to consider is food production. Various theories put the maximum at between ten billion and twenty billion people, depending on the calculations for arable land area and agricultural output based on crop production per hectare. The numbers may be disputed, but there is undisputedly a limit [10].

To continue living decent lives on this planet—Spaceship Earth—the challenge facing us is to find rational ways to use its resources. Rational use here does not mean the unilateral exploitation of resources. It means suppressing the use of resources by using technology intelligently and dramatically changing the very methods of resource use, and we refer to all this as environmental management or environmental protection. Environmental management requires that we rationally limit the human appetite for resource consumption and to do that we need science and technology, as well as a collection of policy and economic methods [11]. Moreover, there are many aspects of this discussion that involve subjective and personal values, so there is also an important role for environmental philosophy, environmental ethics and other dimensions of human thought [12–14].

2.1.5 Recognizing the Limits to Growth

It is possible to predict the sustainable limits of human population and scale of human activities on Earth, but this challenge involves a variety of factors and complex relationships, so the debate is not as simple as one might hope. The first attempt to systematically express an opinion regarding this problem on a global scale was the report by the Club of Rome released in 1970, called *The Limits to Growth* [15–17]. The basis for the report was a simulation of the world's future population, economic activity, industrial production, resource use, and environment, led by Dennis Meadows and Donella Meadows who were at the time graduate students at the Massachusetts Institute of Technology.

It is obvious that Earth has a finite size, so it must be impossible to continue allowing population, gross domestic product, resource consumption, and pollution to grow exponentially forever at a certain percent per year. At a certain point, we will obviously crash into some limits. When the report was released, however, critics attacked it, saying that the analytical methods were crude, and that the report underestimated the capacity of the market economy system to correct itself, as well as the potential for technological advances [18, 19].

An enormous amount of research has been conducted since then to predict the world's future, aided with improved data base and significant advances in computing. Indeed, if we examine the findings of *The Limits to Growth*, they do seem crude in the light of more recent research based on the latest models and vast amounts of elaborate data. To this day, however, the original basic approach and framework of analysis are entirely valid.

Now we must ask how we can circumvent the limits to growth. There are number of possible responses to this question. The first is optimism. The basis for this is a firm belief in the self-regulating or self-correcting nature of economies and societies. This is something close to the belief in the "invisible hand" referred to in economics [20]. If we run out of oil, its price will rise, and rising price will accelerate the development and introduction of nuclear power and renewable energies, thereby preventing any problems. And even if some problems arise, they will eventually be corrected. Humans are intelligent, so they will without fail take rational action before problems become too serious. That is the thinking behind the optimistic response.

Optimism may be a good thing, but do humans really act that rationally? Could our emphasis on economic gain possibly cause irreversible negative changes to the environment? It may be too late to take action if we realize we have exceeded the limits only after exceeding them. Whether it be global warming or the logging of vast tracts of forests in the Amazon, it is extremely difficult to restore original conditions after changes have occurred. Many environmental changes are indeed irreversible [21, 22]. When we think about such risks, it becomes clear that there is an extremely important role for people who take the pessimistic view and continue to ring the warning bells.

What we must pay attention to here is the issue of time scales. If we look at time scales of tens or hundreds of years, mutual feedback works between human activities and their environment to create some kind of balance. Human economic activities change the environment, and then humans are forced to adapt to those changes in the environment. If we look at the short term, however, this mutual relationship may become imbalanced. The result is known as "overshoot" [15].

During Japan's period of rapid economic growth after World War II, industrial production expanded without regard to the environment, setting off pollution problems [23]. The trigger that caused a correction was the sudden oil shock in 1973. The rate of economic growth slowed as a result of the rapid rise in oil prices, and the economy descended into chaos as people panicked and hoarded goods. Triggered by the oil shock, however, Japan's economic growth settled at a more moderate level, and Japanese corporations, particularly in the manufacturing industry, gained a new interest in environmental countermeasures and energy conservation.

The irony is that it was the oil crisis that helped create a better balance between the economy and the environment. Seen this way, the oil crisis may indeed have been an adjustment wrought by the "invisible hand."

2.1.6 The Difficulty of Prediction

While the author was writing this manuscript, from July through December 2008, the international price of crude oil plummeted from a record high of nearly 150 dollars per barrel down to less than 40 dollars per barrel. At the same time the global economy was tossed about by rapid shrinking of credit markets, triggered by the sub-prime loan crisis in the United States, causing a serious downturn in the global economy. National governments around the world found themselves facing an economic crisis on a scale that apparently occurs only once every 100 years. Fervently hoping for an economic recovery, they were using all their tools of financial and fiscal policy: no one was confident that these policy prescriptions would bring about the desired effects. The crisis was foreseen more than a year earlier, but the actual conditions worsened much more quickly than predicted, and pessimism further accelerated a negative spiral of pessimism.

This situation is rich with implications when we consider global environmental problems. The global environmental system, similar to the global economic system, is a complex system involving interactions among innumerable factors. In a complex system such as this, a certain order is generally maintained in overall equilibrium for a certain period of time, but from time to time the response to a small disturbance can cause a large reaction, triggering rapid changes [24, 25]. This sequence may be similar to major accidents in which a small error triggers a large accident through a subsequent chain of errors. If corrective action is taken at an early stage there may be no problem, but once the chain of errors gains momentum, it may run out of control. This risk is something we must not forget when it comes to the operation of Spaceship Earth.

2.2 Environmental Space

2.2.1 Absorptive Capacity/Carrying Capacity of the Environment

There is a certain number of fish that can be raised in one aquarium tank. If you do not put pebbles into the bottom of the tank, grow seaweed, provide aeration with a pump, and so on, the water will become depleted of oxygen, the water will become polluted, and the fish will die. Spaceship Earth is similar.

A certain limit exists for the allowable amount of human activities on the Earth: this could be called "environmental space." Besides the environmental space of the entire planet, a city, a watershed, a lake, or the sea will also have a certain amount of environmental space. For the entire planet or for specific regions, we must ask ourselves how to control the relationships between nature and humanity. What amount of human activity is permitted *quantitatively* within constraints of environmental space? How can we change our activities *qualitatively* if we assume that there are quantitative limits?

The most basic environmental factors for living things involve climatic and meteorological conditions such as temperature, humidity, sunlight, and rain. The climate and meteorological systems—which include the atmosphere and water circulation, that is wind and air currents, evaporation, cloud formation, precipitation, and river flows—are driven by the energy from the sun and determine the survival of living things, humans included.

Climate and meteorological systems were always thought of as being driven by nature and beyond human influence. Today, we know that nature is being changed by the pressure of human activities. Local climates can change if forestlands are converted to farmland and water resources are overused for irrigation. Overconsumption of coal, oil, and other fossil fuels raises the concentration of carbon dioxide in the atmosphere, triggering global warming as a result of the greenhouse effect [4].

Further meanwhile, the chlorofluorocarbons used as refrigerants in refrigerators and propellants in spray cans are themselves strong greenhouse gases. At the same time, they also destroy the stratospheric ozone layer, increasing the amount of ultraviolet light reaching the Earth, especially in places like Antarctica, South America, and Australia, raising concern about the threat of rising skin cancer rates [26].

Changes are also occurring at the city level. Traffic congestion and air pollution are worsening due to increasing automobile traffic, and energy consumption continues to increase from transportation, air-conditioning of buildings, and electrical machines. The loss of urban greenery, replaced by concrete buildings and asphalt roads, is causing the urban heat island effect [27].

The common factor among all these examples is that there are certain limits in the quantity and type of activities that humans are able to do in relationship to the environment. Table 2.1 demonstrates environmental resources allocated to one person. The land area allotted to one person, or the global total land area divided by the world population in 2005, is 20.9 are, of which cultivated arable land area is only 7.6 are (or 760 m^2). Here, 1 are equals to 100 m^2, or 1 ha is 10,000 m^2. Today, this cultivated arable land area can produce the global average of 341 kg of grain per capita, which is just enough to support the increasing world population.

2.2.2 How to Determine Environmental Space

The approaches to calculate and assess the environmental space of a region or the entire Earth depend on the item being considered, on the size of the target region, and on the timescale. In any region, there will be limits to the sustainable size of human population and the amount of activity [28]. For the simplest example, it is worth considering how many people can live on a remote island.

Easter Island in the South Pacific has become famous for its monumental *moai* stone statues. In the third or fourth century AD, this island was apparently covered with subtropical vegetation of palm trees, shrubs, and grass. People migrated to the island, and the population at its peak is estimated at about 20,000. The Clearing of the forests for farming and other uses left the island devoid of all trees. Because the forests were gone the topsoil was eroded away, the farmland depleted, and the lack of wood meant that no longer could anyone even make canoes for fishing. Evidently, wars broke out between different tribes on the island, the human population plummeted, and the people eventually abandoned making their stone statues.

Table 2.1 Environmental space and the scale of human activities (2005)

Category	World	Per capita	Per hectare (ha) of arable land
Population	6.52 billion persons	–	1.31 persons
Land area	136.1 million km^2	20.9 are[a]	–
Agricultural area	49.7 million km^2	7.6 are[a]	–
Arable land and permanent crops	15.6 million km^2	2.4 are[a]	–
Meadows and pastures	34.1 million km^2	5.2 are[a]	–
Cereal production	2.22 billion tons	341 kg	(1.42 tons)[b]
Solar energy	1.74×10^8 million kW	2.67×10^4 kW	(0.343 kW)[c]
Primary energy consumption	1.37×10^4 million kW 10.3 billion tons oil equivalent	2.14 kW 1.58 tons oil equivalent	2.76 kW 2.07 tons oil equivalent
CO_2 emissions	26.7 billion tons	4.1 tons	5.4 tons
Gross domestic product	US$45.3 trillion	US$7,000	US$9,100
Car ownership[d]	923 million vehicles	0.14 vehicles	0.19 vehicles

Source: Prepared from *World Atlas 2008/09*, Tsuneta Yano Memorial Society, Japan and FAOSTAT
[a]1 are (a) equals 100 m^2; 1 ha (hectare) is 100 a (are)
[b]Per hectare of arable land and permanent crops
[c]Per hectare of Earth's surface
[d]2006 data

An interesting comparison is the Edo period in Japan (1603–1868 AD), which maintained an isolated economy during two and a half centuries of seclusion policies [29]. Japan admittedly has a vaster land area than Easter Island, the environment is more diverse, and the country enjoys abundant resources from the mountains, seas, and nature. The Japanese archipelago receives abundant precipitation thanks to its location in the temperate monsoon region, and the forests were able to grow well in mountainous geography. Of particular note, however, is that the size of population that could be sustained by the Japanese islands was entirely determined by food productivity. As a result, years of bad weather meant starvation for many.

2.2.3 Using Technology to Expand Environmental Space

Environmental space is not a fixed quantity. It is possible to increase the amount of space by using technology. Some of the factors that affect food productivity include soil fertility, water, and weather; there are many other factors. Figure 2.2. shows land area harvested and grain production of the world. Today it is possible to produce more than 6 metric tons of grains (rice, wheat, etc.) per hectare of arable land in Japan. In the Edo period, rice was measured in *koku,* with one *koku* equal to 150 kg of rice (2.5 sacks of about 60 kg each), which was the minimum amount of rice a person needed to survive for a year. So productivity today would be equivalent to about 40 *koku* per hectare, but land productivity during the Edo period was about 10–20 *koku* per hectare, much lower than it is today, although it varied by region. Thus, by these

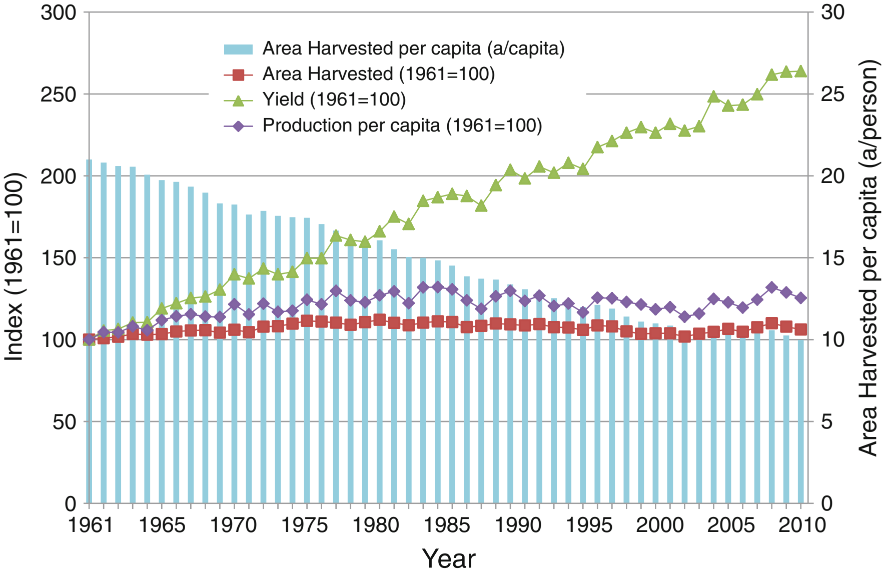

Fig. 2.2 Land area harvested for producing cereals and world grain production. *Source*: Prepared by the author using data from FAOSTAT, Food and Agriculture Organization of the United Nations

figures, it is possible to estimate the livelihoods and economic output of that era, and the Japanese population did not exceed 30 million people during the Edo period.

As of 2002, the total cultivated land area worldwide was about 15.6 million km^2, and grain production per land area was about 1.4 tons/ha. This works out to 341 kg per person. Today's high productivity (measured as harvest amount per hectare) is possible thanks largely to selective crop breeding and the use of agrochemicals such as fertilizers and pesticides. One could say this productivity is the result of technological progress in agriculture. We are already using most of the land suitable for agriculture, however, so large future increases in cultivated land area are unlikely. This limitation means that to respond to population growth we need large increases in output per hectare.

2.2.4 Limiting Factors and Trade: Time and Space

Environmental space depends on how the boundary conditions of time and space are determined. During the Edo period, Japan's carrying capacity based on rice-centered food production was about 30 million people. Today however, Japan depends on food from overseas for about 60% of its caloric intake, and the population is hundred and twenty five million people. These changes are possible because of the benefits of trade.

International trade is one means to increase the environmental space of a region. In the past, European powers solved their land and resource constraints by claiming many other regions of the world as colonies. Today, however, the populations of developing countries in Asia, Africa, and elsewhere are increasing, and their own demand for resources is growing rapidly. One fear today is that the history that unfolded on Easter Island may unfold for the entire world.

Incidentally, some resources can simply not be transferred easily. One of these is land, and another is water. Today groundwater from France is poured into plastic bottles and shipped to convenience stores in Japan, but it is simply not economically feasible to transport large volumes of water from overseas to Japan for agriculture or industry. Yet some people predict that during this century, water shortages around the world will intensify and turn water into a strategic commodity like oil, and huge tankers will be used to transport water around the world.

Today's globalized economic system is supported by transportation systems that can send large amounts of resources to faraway places. This is all made possible by oil. Ships, automobiles, and airplanes cannot operate without oil. Our generation today is swallowing up fossil fuel stocks that we should be leaving for future generations; we are reducing the remaining environmental space on the Earth.

Fossil fuels are a stock of solar energy that was collected through plant photosynthesis during the course of the long history of the Earth, over hundreds of millions of years. If fossil fuel stocks were to run out, and we had to sustain today's high standard of living only with the flow of solar energy, the global population that could be carried would have to be much smaller than today. This change would occur because the land now being used for food production would have to be converted to production of fuels such as bioethanol. Conversely, if it were possible to reduce the global population to half the current level in the next 100 or 200 years, humanity could probably manage quite well using solar energy and biofuels instead of fossil fuels. The use of nuclear power and nuclear safety issues, however, are matters of serious concern.

2.2.5 Climate Change

Global warming, or the rising average temperature of Earth's atmosphere and oceans since the late nineteenth century, is the most pressing problem today, demanding urgent responses from humanity.

There is a correlation between concentrations of greenhouse gases in the atmosphere and the rise of average temperatures on the planet. To limit the predicted warming within a certain range, it is necessary to reduce the total greenhouse gas emissions from human activities to within certain limits. This is none other than the environmental space of the Earth from the perspective of preventing global warming.

At the Earth Summit—the United Nations Conference on Environment and Development—held in Brazil in 1992, countries of the world signed the United Nations Framework Convention on Climate Change (UNFCCC), which requires them to report to the convention secretary on the amounts of greenhouse gases they emit each year. In 1997, the third conference of the parties (or COP3) to the Convention was held in Kyoto, resulting in the Kyoto Protocol, which contains national emission reduction targets for developed countries, including the United

States, Japan, and countries in the European Union. It is not easy, however, to achieve the Protocol's national reduction targets, and in fact the United States withdrew from its commitment to the Kyoto Protocol in 2001, saying that any decision was meaningless if it did not include large emitters such as China and India.

Today, in the 2010s, countries are discussing a shared target of greater reduction in worldwide greenhouse gas emissions to stop global warming. Some countries in the European Union, including the United Kingdom and Germany, are considering bolder reductions of 80% by 2050. This series of activities is a framework to assess and to limit human activities within the boundaries of our global environmental space, from the perspective of allowable limits of total greenhouse gas emissions. This threshold should not be simply interpreted as something that will restrict human endeavors. Why not? Because it is exactly when confronted with constraints that human intelligence is stimulated, innovative new technologies are developed, and new paths forward are discovered.

2.2.6 Air Pollution, Water Pollution

The problem of air pollution is a typical example of environmental problems brought on by modern industry. The sources of air pollution include the burning of coal and oil in factories and power plants, as well as fuel combustion by automobiles. During the 1960s, Japan experienced serious air pollution in industrial cities such as Yokkaichi, Kawasaki, and Kitakyushu.

We can recall how awful the air pollution was in Japanese cities including Tokyo at the time of rapid economic growth in the 1960s. Indeed, in Tokyo at the time, there was a surge in respiratory disorders such as asthma, which we now know is associated with air pollution. The pollution spawned a powerful citizens' movement that demanded prompt countermeasures, and the governments and industry ultimately responded with measures to clean the air. If we are to protect our health, pollutant concentrations in air and water (including rivers, lakes, and oceans) must be maintained below certain levels. Environmental quality standards are used to set those quantitative indicators [23].

To achieve and maintain environmental quality standards, the amounts of pollutants emitted from sources such as factories, buildings, and automobiles must be reduced. For that reduction it is necessary to establish regulations to keep the concentrations of pollutants in emissions and effluent below certain levels. However, even if the pollution concentrations from individual sources are reduced, if the number of sources grows, the concentrations in the environment will not decline. In large metropolises such as like Tokyo and in industrial parks containing many factories, it is not effective to simply regulate individual sources. The answer is to introduce an overall reduction formula that establishes an upper limit on total emissions of air pollutants for an entire region.

In Japan, pollutants from surrounding areas flow into enclosed seas (e.g., Seto Inland Sea, Tokyo Bay and Ise Bay) and lakes (e.g., Lake Biwa and Kasumigaura). The sources of the effluent include households, farms, livestock operations, and

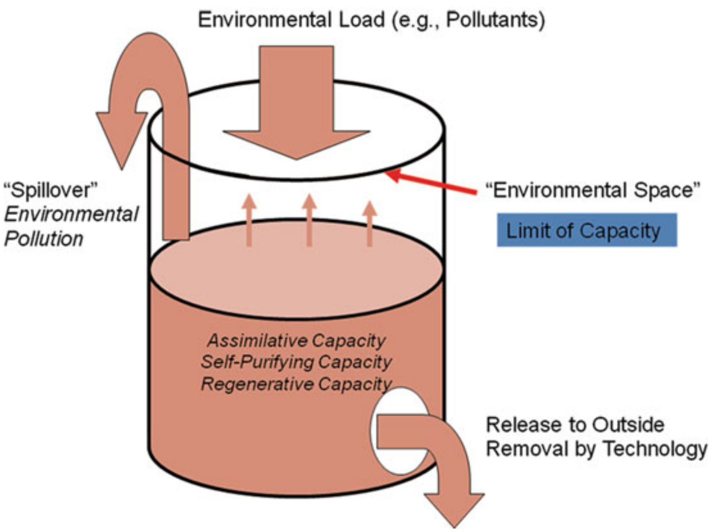

Fig. 2.3 Concept of environmental space

other non-point sources, distributed along the rivers that flow into the seas and lakes. These areas have successfully made large reductions in the pollutant loads from urban households by improving sewage treatment facilities, but it is not as easy to reduce non-point sources such as farmland. For this purpose, a total reduction method has been established that controls the total volumes of biological oxygen demand (BOD) and chemical oxygen demand (COD).

Thus, total pollutant load controls introduced for urban areas, industrial zones, and enclosed seas and lakes are designed with consideration of the regional environmental space for air and water pollution, and can be effective in controlling the total amounts of emissions of pollutants generated by human activities. Figure 2.3. explains this concept of environmental space, where a region is represented by a tank that has a capacity to assimilate and self-clean pollutants and regenerate itself. Some portions of pollutants are released to the outside or removed by control technology. If the incoming load exceeds a certain limit, spillover of pollutants will cause environmental pollution.

2.2.7 Dispersion, Dilution, and the Environment's Self-cleaning Capacity

To quantitatively assess the environmental space for polluting substances, research must be conducted using model-based computer simulations to scientifically analyze and assess a variety of processes involving polluting substances, which can

Fig. 2.4 Contrasting pictures of Dokai Bay in Kitakyushu in the 1960s (*left*) and in the 2000s (*right*). *Source*: Environmental Bureau of the City of Kitakyushu

include dispersion, advection, dilution, chemical reactions in the environment, absorption in soil, bioaccumulation, bio-decomposition, and other mechanisms.

Nature does have the capacity to clean itself. The air pollutants emitted from smokestacks are carried away by the wind and air currents together with the smoke. Effluent discharged into rivers will be diluted by the currents if the flow volume is adequate. Organic waste such as human waste and kitchen waste will be decomposed by microbes in nature. When the scale of human activities was low, there were no major problems with simply flushing effluent into the environment, thanks to the self-cleaning capacity of nature, but there are limits to that capacity. All over Japan, large-scale industrial complexes were constructed along the seashores in some places, and as a result of the discharge of huge amounts of exhaust gases and wastewater into the environment, the environmental space was quickly exceeded locally in many cities and regions.

The water in Dokai Bay of Kitakyushu City is clean and catches of shrimp and fish are abundant today, but in the 1960s it was known as the "Sea of Death" (Fig. 2.4). Factory and household effluent turned the color of water in the harbor black, and it became a cocktail mix of various chemical substances. There were even stories that photographic film could be developed simply by submerging it in this water. In Tokyo's Tama River, large numbers of fish would frequently die off from the discharge of effluent of cyanide compounds and other toxic substances from metal plating factories upstream. Near Minamata City, the Ariake Sea was polluted from organic mercury discharged from a chemical factory, and local residents who ate contaminated fish became afflicted with Minamata disease.

Sulfur oxides, nitrogen oxides and other air pollutants emitted from factories and automobiles are present in higher concentrations near the sources, raising concerns about health impacts on local residents. And that is not all. Pollutants dissolve into raindrops and mist in the atmosphere and are carried along by air currents. They can then be carried hundreds or thousands of kilometers from the original source and then fall as acid rain.

Acid rain in direct contact with tree leaves can cause leaf wilt, and when it falls onto the soil there can also be impacts on the plants as a result of chemical reactions with soil constituents. Generally, the damage is less in alkaline soils such as limestone, but in acidic soils the damage could include large die-offs of trees. During the 1970s and 1980s, many lakes in Sweden and Finland became acidic and fish died off because of pollution carried on air currents from countries such as the United Kingdom and Germany.

In southern Germany, pollution from the industrial areas of the Ruhr region was transformed into acidic rain and mist, and many trees in forested areas known as the "Black Forest" died of the damage. The scene of trees dead and standing or dead and fallen all around was a strange sight to see; the words "death of the forest (*Walt sterben* in German)" convey the general perception one could have there, and it triggered the rise of environmental awareness and the development of new social movements in Germany and other European countries.

The thing we can understand from these examples is that the definition and meaning of environmental space change with scales of time and space. If we take the example of air pollution in cities and industrial areas, from the perspective of protecting the health of local residents it is important to keep the pollution concentrations below a certain level in the vicinity of sources. In the case of acid rain, because the problems can occur thousands of kilometers from the source, it is necessary to think on international and continental scales. In Europe, the Convention on Long-Range Transboundary Air Pollution was concluded in 1979, and under the Helsinki Protocol in 1985, countries agreed to reduce their sulfur oxide emissions by at least 30%. This agreement later became a model for the Kyoto Protocol, intended to stop climate change by setting emission reduction targets for countries.

2.2.8 A Time Bomb Called Chemical Pollution

Discussions to this point have been based on assumptions about nature's environmental restorative capacity and self-cleaning capacity. Water bodies and soil that have been contaminated by toxic heavy metals and chemicals cannot be expected to clean themselves, however.

The mud at the bottom of Dokai Bay and Minamata Bay contained accumulated toxic substances. Because these would then dissolve into the water, the only solution to remove the contaminants was to dredge the mud. Furthermore, in the case of Minamata Bay, it was not sufficient to dredge: the final solution included the capsulation of pollution in place by land-filling 58 ha in the polluted bay.

Soil contamination from heavy metals and other chemical substances is often discovered at former factory sites. In such cases, it is necessary to carry in soil from other locations or to remove the contaminated soil.

The famous Tsukiji fish market in Tokyo has become too small for its needs, so plans have been devised to move it to Toyosu in Tokyo's Koto Ward. When soil analysis was conducted at the planned new site, however, in May 2008 concentrations of benzene, a hazardous substance, were detected at 43,000 times regulated standards. The cleaning of the contaminated soil will reportedly cost tens of billions of yen. Such soil contamination problems occur around the world. In past eras when less attention was given to chemical risks, toxic substances were often buried in the ground and effluent containing toxic substances was discharged onto the ground without much thought for the consequences. Besides such problems with former factory sites, there are also risks posed by laboratories and research institutes that may have used chemicals, radioisotopes, and hazardous substances. In the United States, there are reportedly thousands of such sites, but because of the lack of records, in many cases the pollution is discovered only after the soil is dug up for construction of new facilities on the sites. Such cases of chemicals being suddenly discovered are referred to as "chemical time bombs."

If the area affected by the pollution is limited, cleaning may be possible to some extent, but total removal would be impossible. Polychlorinated biphenyls (PCBs) are one such example. PCBs were often used as insulators in electrical transformers, and were the substances that in 1968 caused the Kanemi Yusho disease, a case of poisoning from contaminated cooking oil from the Kanemi Company in Japan. Because these are extremely stable chemicals, they do not easily decompose, and can easily accumulate in the bodies of animals, particularly in fatty tissue, if they enter the food chain. High concentrations of PCBs have been detected in the bodies of Inuit people in Alaska. PCBs dissolved into seawater become concentrated in fish, then further concentrated at higher levels in the bodies of seals that eat the fish, and remain in the bodies of the people who eat the seals.

Similar problems occur with agrochemicals such as dichlorodiphenyltrichloroethane (DDT) and benzene hexachloride (BHC). Common factors of these chemicals are that they are persistent (do not easily decompose), are bioaccumulative, can travel great distances, and are toxic to human health and ecosystems. The general term for them is persistent organic pollutants (POPs). Because of concerns about POPs pollution on a global scale, the Stockholm Convention on Persistent Organic Pollutants was concluded between countries and entered into force in 2004.

2.2.9 Environmental Control on Spaceship Earth

In the past, the world was covered with a much greater area of forest than today. Humans increased their food production by converting the forested land to agricultural land, allowing the human population to grow. The Industrial Revolution resulted in dramatic advances in science and technology and made possible the mass production of products. The benefits extended also to agricultural production, where the large-scale use of fertilizers and pesticides, as well as the mechanization of agriculture resulted in large increases in agricultural harvests per hectare. But humanity cannot completely monopolize the Earth for its own purposes. In recent years, the use of Earth observation satellites has allowed scientists to learn, little by little, about the conditions on Mars, Jupiter, and other planets in our solar system. Among the most astounding realizations are the findings that human life on Earth is thanks to a miraculous combination of conditions that make it possible for us to live here.

The expansion of human activity is destroying the exquisite balance of the global environment. Thus, it must be the hand of humanity that corrects the disruption. It is to this end that the international community has decided to abolish the manufacturing and use of chlorofluorocarbons (Montreal Protocol) and to reduce the emissions of greenhouse gases (Kyoto Protocol). These steps could be seen as none other than measures for environmental control on Spaceship Earth. If such measures fail, the fate of humanity may turn out similar to the fate of fish in a tank after the environmental controls fail. Spaceship Earth is complex, however, and running it properly is much easier said than done.

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Chapter 3
Understanding the Global Climate System

3.1 Water Planet: The Earth

3.1.1 Earth's Atmosphere

In 1961, the former Soviet Union succeeded in launching the first manned satellite into space. It was Yuri Gagarin, the cosmonaut on that spaceship, who commented that from space the Earth appeared blue, but what he actually said were poetic words to the effect that "The color of the Earth was a soft, pale blue, and its border with the endless black of space was a very gentle curve and beautiful." When we hear "blue" we often associate it with the blue color of water, but the blue of the Earth as seen from space is actually the blue resulting from the diffusion of light through the atmosphere. This is the same reason the sky above us looks blue.

The Earth is wrapped in an atmosphere. The troposphere accounts for 80% of the mass of the atmosphere and extends 11 km above the surface of the Earth. If the Earth were compared to an egg, the atmosphere would actually be considerably thinner than the eggshell. This thin layer is also where we find the oxygen that is so essential for our survival. The oceans and atmosphere absorb the energy from the sun, which drives an enormous circulation system consisting of the tide, ocean currents, wind, air currents, evaporation, and precipitation. It is this system that defines the existence of a multitude of living things on the Earth.

Today the amount of carbon dioxide (CO_2) in the global atmosphere amounts to about three trillion tons. Every year about 25 billion tons are emitted from the consumption of fossil fuels, and about half that amount remains in the atmosphere. If the current trend accelerates further, the concentrations of carbon dioxide in the atmosphere will double in the next 100 years, driving further global warming. The problem is the current extent and speed of growth of human activities in relationship to the size of the Earth [1].

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3.1.2 Water Circulation

The Earth is known as the water planet. Its oceans hold 13.7×10^{18} tons of seawater. Every second, 4.20 million tons of water evaporate from ocean and land surfaces, and the same amount falls as precipitation. These figures give a sense of the scale of cycling of evaporated moisture and precipitation that is circulated by energy from the sun [2].

On the Earth today, ice sheets or glaciers are only present on the poles, as well as in high mountains in the Himalayas, the Alps, the Andes, and other very high mountains, but in the past there were periods when the entire Earth was covered with ice and other times when there was none.

The 4.6-billion-year history of the Earth since the birth of the solar system is magnificent. The story of geotectonic movement, volcanic activity, meteorites, the birth and evolution of life, and the ascent of *Homo sapiens* is a fascinating one. There were periods when huge trees much thicker than those growing today grew on the Earth and gigantic dinosaurs flourished, and other times when the entire Earth was a snowball covered with ice a thousand meters thick, and times when many species went extinct [3, 4].

Today carbon dioxide in the atmosphere has a concentration of about 360 parts per million (ppm), but if this were to fall below 10 ppm, the Earth could become a snowball again. In the past, after being an ice ball, the Earth would warm up again and all the ice would melt. This behavior occurred because volcanic activity supplied huge amounts of carbon dioxide to the atmosphere. The partial pressure of carbon dioxide is said to have been as high as 0.1 atm sometime in the past, an amount about 30 times the current level.

It is not only carbon dioxide but also other atmospheric constituents that have changed dramatically, including the amount of oxygen in the air. Changes such as these occurred over time spans of millions to hundreds of millions of years. The important concerns for us now are changes over the next 100 years or so—roughly one human lifetime—but we are today facing the most dangerous levels of global warming in the past 10,000 years.

3.2 Global Climate

3.2.1 Global Warming in an Interglacial Period

During the 1970s, the majority of books on climate change were expounding the theory that the Earth would eventually enter a period of cooling. The Earth today is in an interglacial period, so it was assumed that eventually the planet would return to a glacial period. Some publications did touch upon the greenhouse effect caused by an atmospheric buildup of carbon dioxide and the potential for global warming, but the literature on this matter was very basic. It was only in the 1980s that scientists became truly concerned among themselves with global warming.

The solar system and the Earth were formed about 4.6 billion years ago, and since that time the Earth has gone through many cycles of warming and cooling in its history. During the past several hundred million years, there have been repeated glacial periods on a cycle of between 40,000 and 100,000 years, and the most recent glacial period ended about 15,000 years ago.

A convincing explanation for the arrival of the cyclical glacial periods is that they are caused by cyclical variations in the Earth's orbit around the sun: this is known as the Milankovitch theory [5]. The point in the orbital path closest to the sun is known as the perihelion; it is at that point when the distance from sun to Earth is the shortest that the Earth becomes hotter. Furthermore, the orientation of the Earth's rotational axis (or geographic axis) is not constant. Even a slight increase in the inclination of the axis will increase the amount of incoming solar energy to the poles, which will cause ice to melt, with implications for the global climate.

The theory that the Earth is currently in an interglacial period and that a glacial period will return someday is probably correct. The theory that the Earth will undergo warming from greenhouse gases including carbon dioxide emitted by anthropogenic sources is also correct. The global warming that the world is concerned about today specifically means the rise in the average temperature of Earth's atmosphere and oceans since the late nineteenth century, and this global warming is occurring during an interglacial period. If one thinks about it this way, many common misunderstandings will evaporate.

3.2.2 Time Scales: The Key to Understanding the Issues

The arrival of a glacial period is a phenomenon that occurs with a frequency of tens of thousands of years, but the increase of atmospheric carbon dioxide from anthropogenic emissions is something that has been occurring in just the past 200 years or so. From this point forward, will the Earth warm up or cool down? To address this question, the concept of time scale is very important. For what period of time will the warming continue, and when will cooling begin again? It is difficult to predict these accurately, but one hint of an answer comes from examining the changes in the global climate after the end of the most recent glacial period.

The Earth from about 7,000 to 5,000 years ago was considerably warmer than it is today. There are various scientific terms to describe this period, including the climatic optimum (hypsithermal) period and thermal maximum [6]. During this period, the global average temperatures were between about 0.5 °C and 2 °C warmer than in the mid-twentieth century. The degree of warmth actually depended on the latitude, season, and location. Near the North Pole the average annual temperatures were more than 4°C warmer than today, while scientists believe that temperatures at mid- and lower latitudes, closer to the equator, were not much different from today. Evidently, Scandinavia and other locations in northwestern Europe were warmer, but conversely, southern Europe was even colder than today. These conclusions are drawn based on analysis of tree rings and of fossilized pollen stored in the ground layer.

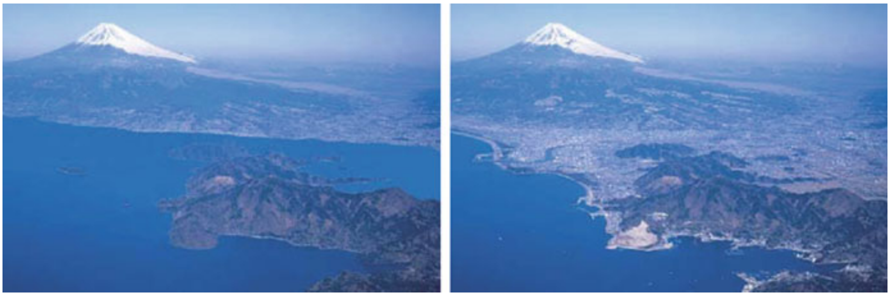

Fig. 3.1 Mt. Fuji and Suruga Bay in the Jomon period (*left*) and today (*right*
Source: Computer graphics study by Takanori Sato. http://user.numazu-ct.ac.jp/~tsato/tsato/geoweb/jomon/)

3.2.3 Jomon Marine Transgression

The early Jomon period in Japanese history lasted from about 6,000 to 5,000 years ago, and this period corresponded to the hypsithermal. The sea level at the time was 4 or 5 m higher than it is today, and because the ocean came much further inland than today, it is referred to as the Jomon marine transgression (as imaged by Fig. 3.1). Evidence of this situation is provided by the discovery of ancient shell mounds in Saitama Prefecture and other locations inland, even 100 km distant from the present sea in Japan. Vegetation was also different. The land was covered with evergreens and broadleaf deciduous forests. At the Sannai-Maruyama site in what is now Aomori City (northern Japan), one can find the 4,000–5,500 year-old remains of a Jomon period settlement, which shows signs that people tended many chestnut trees, a species that normally grows in warmer regions. The site is on a hill located 3 km from the present-day coastline, but in those days the sea came right to the base of the hill.

Starting about 5,000 years ago, the Earth gradually began to cool. The warm region around Aomori eventually became cooler, making it unsuitable to grow chestnuts as a food for the people. The sea level gradually dropped and sandy beaches began to appear, but these changes would have posed difficulties for fishing. Until then, people could catch fish close to where they lived, but now they were forced to row out further offshore. At its peak in the early Jomon period, the human population on the Japanese archipelago is estimated to have exceeded 200,000 people, but it is estimated that the population dropped to less than 100,000 in the late Jomon period, from 3,000 to 2,300 years before the present day.

After the hypsithermal, it appears there was a global cooling trend. This change apparently occurred over several thousand years. The change was not exactly as simple as that, however, as there were alternating warmer periods and colder periods on a cycle of several hundred years, which had enormous impacts on the emergence of civilization and human history. One could say that these changes virtually created human history.

3.2.4 Medieval Warm Period and Recent Cooling

In Europe, during the Medieval Ages (about 800–1300 AD), the climate was warmer, so it is known as the Medieval Warm Period. Conversely, the period 1400–1900 AD was cooler, so it is known as the Little Ice Age, or the modern Mini Ice Age. Reports by the Intergovernmental Panel on Climate Change (IPCC) and others have verified the Medieval Warm Period and Mini Ice Age as fact in Europe, but they take the position that this conclusion cannot be applied worldwide. However, even if the warming was limited to Europe, the Medieval Warm Period and Mini Ice Age both lasted a few hundred years, which indicates that changes on time scales such as these do occur worldwide, or at least in certain regions [7].

The global climate is controlled not only by variations in the Earth's orbital path and rotational axis and by changes in concentrations of greenhouse gases, but also by other factors, such as sunspot activity and material ejected from volcanic activity. Volcanoes can eject huge amounts of ash, and if this rises into the stratosphere and remains there for a while, the amount of sunlight reaching the Earth's surface will decrease, resulting in a cooling of the climate. Furthermore, many times immemorial volcanic activity has emitted huge amounts of carbon dioxide into the atmosphere from the Earth, contributing to warming.

One theory suggests that the modern Mini Ice Age was associated with volcanic eruptions. The Great Tenmei Famine occurred between 1782 and 1788 in Japan. At about this time, in 1783, two large volcanic eruptions occurred in Iceland, and in Japan, Mount Iwaki and Mount Asama also erupted. It is possible that these eruptions caused climate cooling and crop damage in the entire Northern Hemisphere, including Europe and Japan, and some theories postulate that these were the cause of the Great Tenmei Famine in Japan, mostly in the Tohoku (northeast) region of the country. Furthermore, in Europe, the climatic cooling may have been a factor contributing to the French Revolution in 1789.

The Great Tenpo Famine occurred in Japan from 1835 to 1839 and the Great Irish Famine from 1845 to 1849. The Great Irish Famine was caused by a potato blight, and 1.5 million people may have died in Ireland from starvation or disease caused by malnutrition. Agricultural productivity at the time in Europe was low because of the cooling of the climate, but food shortages were mitigated somewhat thanks to potatoes, which would grow even in depleted soil. After this famine, European countries experienced skyrocketing prices of farm produce, and this was a major reason that motivated people to emigrate to the new continent of America. Viewed in this way, although the famine in Ireland may not have been directly triggered by crop damage from the cooler temperatures, the cooler climate was certainly a contributing factor.

3.3 The Advance of Global Warming

3.3.1 IPCC Fourth Assessment Report

It is virtually certain that the Earth will experience warming during the twenty-first century. The cause is carbon dioxide and other greenhouse gases emitted from human activities. Some still hold doubts about carbon dioxide as a major culprit causing the warming, but there is no question that the Earth's temperature has been rising recently.

The Intergovernmental Panel on Climate Change (IPCC) has the mandate of gathering together the latest available scientific knowledge about global warming, and conducting analysis and assessments on response technologies and policies, as well as impacts of warming. It publishes "Assessment Reports" every 5 years or so, bringing together scientific knowledge from several thousand experts worldwide on the topic of global warming, and has significant influence on international politics as well as national policies [8–11].

The IPCC's Fourth Assessment Report, released in May 2007, stated clearly as a scientific fact that warming is under way, and concluded that human activities are the cause. Figure 3.2 shows the change in the atmospheric concentration of carbon dioxide, while Fig. 3.3 shows the results of analysis of changes in average surface temperatures worldwide, based on meteorological data collected continuously from various locations worldwide since the middle of the nineteenth century. To smooth out the large variations in annual data, a thick line is used to show changes in the 5-year moving average. This approach levels out the annual variations, clearly showing a rising trend in temperature. Quantitatively, the surface temperature of the Earth rose by 0.74 °C (± 0.32 °C) over the 100 years from 1905 through 2005.

This figure shows that temperatures have been increasing since the 1980s, by about 0.5 °C over a 20-year period. It was during the 1980s that climate scholars began to seriously discuss the possibility of global warming from carbon dioxide and other gases. The IPCC was established in 1988. At first, the scientists who predicted warming may not have been entirely confident in their predictions, but more recently the degree of certainty has been grown increasingly stronger as a result of the growing body of observational data.

A further warming of between 1 °C and 6 °C is being predicted for the next 100 years. The actual amount of warming will be affected by the amount of carbon dioxide emissions, which in turn depends on the amount of fossil fuels used for human economic activities. Besides carbon dioxide, other powerful greenhouse gases include methane and chlorofluorocarbons and their atmospheric concentrations are also a matter of great concern.

The gases covered by the United Nations Framework Convention on Climate Change are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), CFC alternatives (i.e., hydrofluorocarbons, or HFCs, and perfluorocarbons, or PFCs), and sulfur hexafluoride (SF6). Today the greenhouse effect caused by substances other than carbon dioxide is becoming stronger, but carbon dioxide still accounts for a little more than half of the total effect. The G8 Summit in 2008 agreed to seek international con-

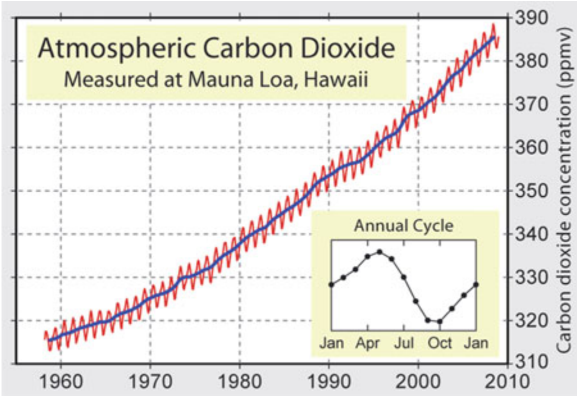

Fig. 3.2 Change in the atmospheric concentration of carbon dioxide
Source: http://en.wikipedia.org/wiki/File:Mauna_Loa_Carbon_Dioxide.png

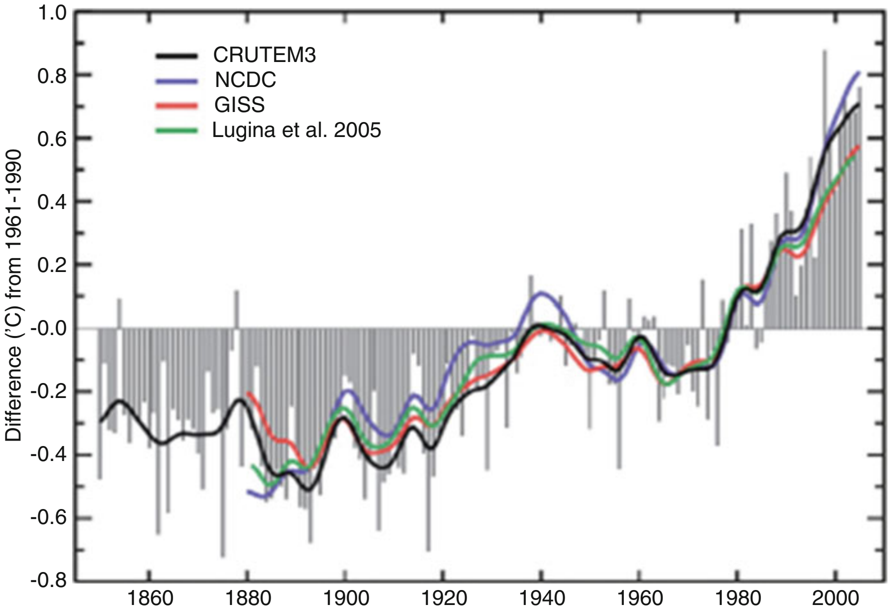

Fig. 3.3 Global surface air temperatures during the past 150 years
Source: IPCC AR4 WG1 Report, Cambridge University Press, Figure 3.1
Note: Annual anomalies of global land-surface air temperature (ºC), 1850 to 2005, relative to the 1961 to 1990 mean for CRUTEM3 updated from Brohan et al.(2006) The smooth curves show decadal variations. The black curve from CRUTEM3 is compared with those from NCDC (Smith and Reynolds, 2005; blue), GISS (Hansen et al.,2001; red) and Lugina et al.(2005; green)

sensus to reduce worldwide emissions of carbon dioxide and other greenhouse gases by more than 50% by the year 2050. Although the United States had been dragging its feet, at last it too agreed on the need to take drastic action on climate change.

The global climate system could be compared to a large rock sitting on slope. At first it is very difficult to move, but once it starts rolling, the motion becomes very difficult to stop. If it starts to accelerate, it could roll down the hill with frightening speed. The continued melting of ice in places such as the Arctic and the Himalayas since the year 2000 is beginning to fit this metaphor more than ever.

3.3.2 The Speed of Global Warming

There are two major problems with global warming. First, it is being caused by humans. Second, it is advancing quickly. Climate change in the past was a natural phenomenon, and all humans had to do was to adapt to it. Since the industrial revolution, however, anthropogenic emissions of greenhouse gases have been growing at an accelerating rate, and it is humans that are causing the current problem of global warming. Humans are causing global warming through all their actions that consume energy—room heating, television viewing, computer use, and automobile transport. We know these facts today, but not enough people are willing to abandon their lifestyles of convenience and comfort.

As mentioned earlier, it was the 1980s when global warming from carbon dioxide and other greenhouse gases first began to attract attention, and from then until the present day, the global average temperatures have been rising noticeably. Changes in the Earth's average temperature are affected by a variety of concurrent cycles lasting tens of thousands of years, thousands of years, and hundreds of years. During this present warming period, it appears that the warming effect caused by greenhouse gases is starting to be expressed more strongly than the other factors that affect climate.

If human production and consumption activities continue to grow at the current pace, within roughly the next 50–100 years, basically between 2050 and 2100, the concentration of greenhouse gases in the Earth's atmosphere may rise to as much as two or three times the current level, which could cause warming to temperatures that exceed the warmest period that ever occurred in the past 10,000 years. In such a scenario, the global warming could occur extremely rapidly, on a short timescale of decades. This type of change would be at a rate that could be detected through an individual's own observations and experiences during one human lifetime. This shift could mean that by the time people who are in their teens and twenties today reach old age, the winter temperatures in San Francisco would be as warm as they are in Los Angeles today, and the winters in Tokyo would be like Okinawa today. These are changes that people could clearly notice themselves.

3.3.3 Global Warming: Accelerating

Once a warming trend begins, the effects grow like a snowball. Global temperature increases are mitigated somewhat thanks to the reflection of solar light back into space by the surface of ice and snow in places such as the Arctic, Antarctica, the Himalayas, and the Alps. As the ice is melted by rising temperatures, however, the land and sea surfaces that were previously covered by ice will be exposed, allowing solar heat to be absorbed and warming the land and sea surfaces, further accelerating the rate of melting.

Indeed, since the beginning of this new century, the recession of glaciers in the Himalayas and Andes has been noticeable to the eye. The shrinking of the Arctic ice pack during the summer months has also been dramatically rapid. The author was raised in a part of Japan that typically had heavy snow in winter. When we did not have enough places to pile up the shoveled snow, we would spread dirt on top of the snow to melt it as quickly as possible. If a lot of rain fell, the runoff would also create tunnels under the snow pile, which would increase the rate of melting. The same type of thing is happening with glaciers. If a glacier melts a little, streams form beneath it. If that happens, the glacier begins to slip forward more easily, and when pushed, will break loose from the ground below it. It is in this way that large chunks of glaciers in Antarctica are collapsing and falling into the sea.

The ocean plays an enormous role in regulating the global environment. Many of the pollutants from terrestrial sources end up in the oceans after being carried down rivers or being dissolved in rain. The environmental space of the oceans is enormous, but even so, it still is finite. About half the carbon dioxide emitted into the atmosphere from the combustion of fossil fuels such as coal, oil and natural gas is eventually absorbed by the oceans. A huge amount of carbon dioxide is dissolved by the oceans, but solubility drops as the water temperature rises, meaning that the capacity of the oceans to absorb carbon dioxide declines, with the result that the oceans will start to release large amounts of that same gas into the atmosphere.

Meanwhile, serious impacts also affect marine life when the oceans absorb more carbon dioxide. The rise of carbonate concentrations in the seawater could make certain marine regions more acidic. If that happens, the calcium carbonate shells of plankton and other basic creatures in the marine food chain will dissolve, causing impacts on marine life over vast regions of the oceans.

The death of coral caused by warmer water temperatures leads to another serious problem. If seawater temperatures rise above 30 °C, the *zooxanthellae* (photosynthesizing unicellular algae) that live in symbiosis with the coral will decline. Coral get their energy from the photosynthesis of these *zooxanthellae*, and if warm temperatures continue for too long, the coral will die. What may have been a colorful red and yellow reef will die and turn white—a phenomenon known as *coral bleaching*. Coral plays the important role of sequestering carbon dioxide into the oceans in the form of calcium carbonate, so the death of corals will reduce carbon sequestration and further accelerate warming.

What impact will warming have on the climates of regions around the world? The answer depends on the interactions of factors such as seasonal air pressure distribution, amount of sunlight, sea surface temperatures, and other factors, so precise predictions are difficult to make, but one major cause for concern is potential changes in precipitation patterns. Warming could increase the amount of evaporation from the sea surface, so total rainfall may increase, but there could be geographic and seasonal variations in rainfall distribution. Even though the rainfall may increase in the Asian monsoon region, the inland continental regions in Eurasia may receive less rainfall and become dry out. In addition, although giant typhoons and hurricanes could bring heavy rainfall during the rainy season, dry seasons may end up with absolutely no rainfall, and the dry seasons may last longer.

Right now, the Amazon and other areas are already rapidly losing their tropical rainforests, but global warming could further accelerate desertification and the loss of forests. Furthermore, if the permafrost in Siberia and other cold regions warms up, the methane and other greenhouse gases now locked up in the frozen ground could be released into the atmosphere.

Clearly, warming has a variety of impacts on the global environment, and those impacts have feedback effects that will further accelerate the pace of warming. The further the warming trend continues, the more momentum it gains.

3.3.4 Large-Scale Ocean Circulation: The Great Ocean Conveyor Belt

Large-scale ocean circulation has an enormous impact on global climate. There are two types of circulation: wind-driven (powered by the wind), and thermohaline (affected by water temperature and salinity). It is the latter that has the greatest impact on the global climate.

Seawater is cooled in the cold polar regions of the planet whereas it is warmed near the equator. Cold saline seawater is dense and tends to sink down to deeper levels. Thus, in the North Atlantic and regions near the Antarctic, it sinks as deep as 2,000 m below the surface, a process referred to as overturn. This water then circulates the world as "deep water," and rises again (upwelling) where it is warmed in tropical and subtropical regions (in the Pacific Ocean, Atlantic Ocean, and Indian Ocean). The warmed seawater returns again as surface water to the place where it previously overturned and sinks again to become deep water. This current, referred to as the ocean conveyor belt, functions to carry solar energy absorbed in tropical and subtropical seas toward the poles (Fig. 3.4). This phenomenon explains why some regions of the world, such as the Scandinavian Peninsula on the continent adjacent to the North Atlantic region are comparatively warm despite their relatively high latitudes. The rate of flow of the deep currents is very slow, taking about 2,000 years for one complete cycle of the world's oceans.

If Arctic ice continues melting, the freshwater will dilute the overturning seawater, reducing its salinity level. If that happens, the force of sinking will be weakened, and the motion of the conveyor belt will also be weakened. If this happens, the impacts on continental climates will be enormous. The ocean conveyor belt stopped numerous times during the Earth's history, but if such a condition occurs, some regions of the planet may become colder even while the Earth's overall temperature increases. Thus, it is possible that the climate will become colder in countries of Western Europe and the Scandinavian Peninsula and other places where it is relatively warm for the latitude. Countries of the European Union have a good reason to be keen to take global warming countermeasures.

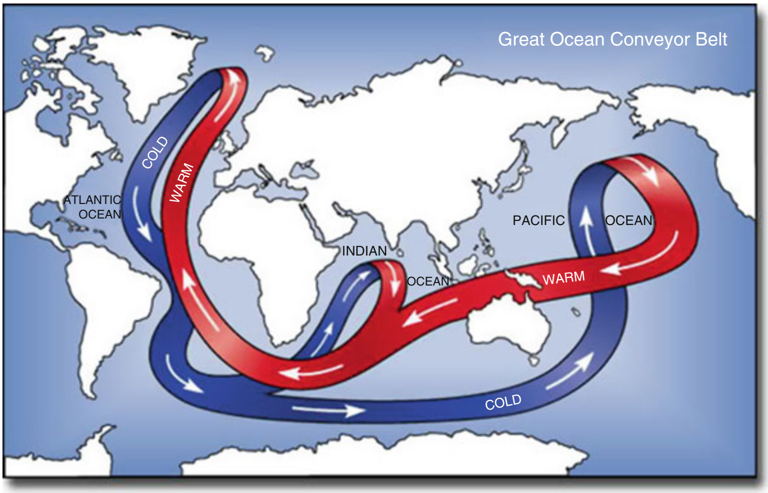

Fig. 3.4 Great ocean conveyor belt. *Source*: NASA (National Aeronautics and Space Administration, http://science.nasa.gov/science-news/science-at-nasa/2004/05mar_arctic/

3.4 How Can We Know the Future?

3.4.1 Future Predictions

Today, the average temperature of the Earth's surface is steady at about 15 °C. These conditions have created a favorable environment for human life for many developed countries in the middle latitudes, including many European countries and Japan. However, if there is an increase in the amount of greenhouse gases such as carbon dioxide, which today accounts for only 0.036% of the atmosphere, the Earth will warm up. If humanity continues to carelessly burn fossil fuels such as oil and coal as it is doing now, the average temperature of the Earth in 100 years is likely to increase between 2 °C and 3 °C, according to conservative estimates, and potentially by as much as 6 °C.

If the temperature rises by 6 °C, areas such as the American Midwest, which is now one of the "granaries of the world," may turn into deserts, and countries in the lower latitudes near the equator will become unbearably hot. It is also possible that warmer climates in northern Canada, Siberia, and in northern Europe may make these regions more comfortable to live in, while the melting of Arctic ice may turn the Arctic Ocean into a strategic route for marine transportation. Not only that, in a few hundred years, sea levels are likely to rise 5 or 6 m above current levels.

3.4.2 *Weather Forecasts and Global Warming Predictions*

Discussions about the future of climate change are more about possible scenarios than about accurate predictions. Enormous progress has been made in research to recreate the global climate system by simulations using supercomputers, and the certainty and accuracy of predictions are steadily improving as more observational data come in. Nevertheless, it is extremely difficult to make completely accurate predictions. This situation is very similar to the problems relating to the daily weather forecast. Although the accuracy of weather forecasts has become very good, they still miss the mark quite often. Nevertheless, forecasts of the landfall of a typhoons or occurrence of a heavy rainstorm become more accurate immediately before the events, so it is always safer to take them seriously. People who try to interpret a forecast to their own liking and go about outdoors while ignoring an approaching storm are likely to run into trouble.

Global warming predictions today could be described as being at the level equivalent to that at which we can identify the emergence of a tropical low pressure system over the Pacific Ocean and predict that it will develop into a large typhoon. We can imagine a number of scenarios for how big the typhoon will become and what path it may take, but we are not yet at the stage where we can accurately predict what is going to happen. Nevertheless, because there is a relatively high likelihood that it will develop into a super typhoon, and that it may directly strike the region you live in, you should take preparations seriously. You are free to hope that its path will miss you, but if you are complacent and simply count on being lucky, there is a strong chance that you will face some hardship.

At least one big difference exists between weather forecasts and climate change predictions: while weather forecasts are almost entirely about natural phenomena, climate change prediction is about phenomena that involve human causes. Climate change trends will be strongly determined by the impacts of the future actions of human society. This may be an extreme scenario, but if humanity were to immediately cut fossil fuel consumption by more than 90%, global warming caused by human factors would cease to be a problem. Furthermore, in contrast to short-range weather forecasts that predict the weather over the coming week, days, or hours, climate change predictions picture the next 50–100 years of the Earth's future.

3.4.3 *Attitudes About the Future*

Humans have a tendency to believe that which is convenient for them and to avoid believing that which is not. We also tend to be driven by economic motives. If there were promise of big profits, some people would tend to ignore even warnings of an approaching typhoon or storm. Even worse, if a government or industry believes that certain information may be "inconvenient," they will sometimes actively suppress that information or distort it to their advantage.

In her 1962 book, titled *Silent Spring*, Rachel Carson, using the example of a spring when no birds sang, called attention to the risks of using the pesticide DDT and other chemical substances [12]. The chemical industry attempted to counter her assertions by pouring enormous funds into research, and tried to convince the world that pesticides were not dangerous. She was not a scientist in this field, and her arguments did actually contain some scientific errors, so she had to fight hard to defend herself. Her work, however, elicited a huge response from the American public, and eventually the United States government had to change its pest control program.

During the 1970s, the world was alerted to the potential for chlorofluorocarbons to destroy the planet's ozone layer, and the need for measures to stop their use became an international issue. Eventually, the manufacturing, use, and trade of chlorofluorocarbons became regulated under the Vienna Convention (1985) and Montreal Protocol (1987), although the path to get there was not easy. At the time, industries took a negative stance and opposed international regulations, claiming that the impacts of regulation on the economy and employment would be too high.

In 2007, former vice president of the United States and 2004 presidential contender Al Gore was co-recipient, with the IPCC, of the Nobel Peace Prize for his contributions to the spread of awareness about global environmental issues. The title of his book was *An Inconvenient Truth* [13].

In Japan, concern about global warming is extremely high, and this issue is covered extensively on television and in print and other media, but the tone of the media coverage here has been different from what the public has seen in most of the domestic media compiled in the United States. The Bush Administration (2000–2008) held the view that global warming was still no more than an academic theory and rejected the idea that it was occurring. Thus, the response of Americans to global warming has been subdued.

The past 100 years of history have been filled with scientific and technological progress, major wars, and much change. If we reflect upon the past, we realize how difficult it is to predict the distant future. Nevertheless, there is nothing more unsettling than trying to navigate the seas without a compass. It is exactly because Columbus believed in the existence of a new continent that he succeeded in crossing the ocean. Even though there is much uncertainty about the future of the global environment, it is essential that we share some common ideas about trends and our overall direction. The IPCC, established to deal with global warming issues, is intended to negotiate exactly those needs.

3.4.4 Model-Based Simulations

The purposes of simulations using models are to identify the various factors that drive and affect complex systems, to clarify the interrelationships among the factors, and then, by combining the factors in certain ways, to test the model and see how closely it recreates the real situation. The first warning to the world from this type of research was *The Limits to Growth*, published by the Club of Rome in 1971

[14]. Although the contents of this report attracted much criticism, it still deserves the highest praise for analyzing humanity's activities and the Earth's resources together as one system.

It is, of course, desirable that models recreate reality as accurately as possible, but there will always be limits to the number of variables and parameters that can be included in any analysis, even when using a powerful computer. The number of factors involved in real systems could almost be described as infinite, In some cases, even small factors involved in a complex system could, through nonlinear effects, trigger huge changes in the system.

It is worth asking this hypothetical question: If a computer were created that could perform calculations thousands of times faster than today's computers, would predictions be more accurate? In response, there are two problems involved here. The first is the enormous number of factors that make up the global climate system. The second is the inherent complexity of the system. For simulations, the entire world surface is divided into grids, and the finer the divisions, the larger will be the number of unit cells. In addition, the oceans and atmosphere require vertical divisions as well. Also the more precise the units of time used, the more numbers that will have to be processed. On top of this, it is also necessary to solve the equations numerically to determine variables such as the movement of air and water, as well as temperature, humidity, cloud formation and rainfalls. The computations will become monumentally large. This is the biggest challenge, but if computers make further dramatic advances, and we also obtain many more observational data, we will likely be able to overcome the technological hurdles someday.

The second problem, which is of a different nature, is that we are dealing with complex systems. We sometimes hear something like "if a butterfly flaps its wings in Beijing, it will cause a hurricane in New York." This concept originated from a meteorologist named Edward N. Lorenz, who noticed that if the values of input parameters were changed only slightly in familiar simple equations, the results could be dramatically different [15]. This sensitivity can be true of nonlinear equations. If a system contains nonlinear equations, it becomes extremely difficult from the outset to predict outcomes, but if the outcome is dramatically affected by the value of an input parameter, it inherently becomes extremely difficult or even impossible to make an accurate prediction.

Furthermore, human activities—economics and politics and the like—have the power to affect the amounts of greenhouse gases emitted. And even though humans do have the power to shape those activities, the reality is that the interests and ulterior motives differ with each country and even with each person. As a result, people may not be able to control emissions as much as they wish they could. When concerned with systems of this nature, it is critical to refine the data as much as possible to reproduce the actual conditions. At the same time, it is important to pay attention to the mechanisms and consider what factors interact to cause certain effects in the phenomenon being studied, and to seek approaches and insights into ways the system should be managed.

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Chapter 4
Biodiversity and Ecosystem Service: Indicators of the Global Environment

4.1 Biodiversity: Gifts of Nature

4.1.1 The Threat of Mass Extinction

Next to global warming, another major issue of this century is the crisis of biological diversity. In fact, many biologists believe that a mass extinction of species is already underway [1–4].

Within the next few decades, the habitat of many wild animals—chimpanzees, gorillas, orangutans, lions, tigers, elephants, rhinoceros, and so on—will be affected by further destruction of their wildlife habitat, and experts are concerned that within a few decades, these animals will only be able to live in the limited confines of protected areas and zoos. It is not only these large mammals that risk extinction, but a surprising number of other species as well [5].

About 1.75 million species have been discovered and named to date, although there are differences in the species definitions and classification methods used by experts. Actually, an even greater number of species has not yet been discovered: some experts believe the total number of species may be 30 million or even 100 million [6].

Covering only 7% of the world's land area, tropical forests are a treasure trove of life, providing habitat for more than half of all species. The tropical forests of Central America and Southeast Asia, in particular, are host to an extremely high number of species, earning the countries in these regions with so many endemic species the label of "megadiversity" countries. However, encroachment by human development is causing a rapid decrease of tropical forest area, triggering the extinction of many species [7].

According to the Red List of Threatened Species released by the International Union for the Conservation of Nature (IUCN), as of 2008, there were 164,52,189 described species, and research into 44,838 of these species found that a total of 16,928 plant and animal species were endangered (Table 4.1). This number includes 1,141 species of mammals (21% of all described mammals) and 1,222 species of birds (12% of all described birds). Of these, 150 animal and 11 plant species are in Japan [8, 9].

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Table 4.1 Number of endangered species (2008)

	Estimated number of described species (*X*)	Number of species evaluated by 2008 (*Y*)	Number of threatened species in 2008 (*N*)	Threatened species (%)	
				N/*X*	*N*/*Y*
Vertebrates					
Mammals	5,488	5,488	1,141	21	21
Birds	9,990	9,990	1,222	12	12
Reptiles	8,734	1,385	423	5	31
Amphibians	6,347	6,260	1,905	30	30
Fishes	30,700	3,481	1,275	4	37
Subtotal	61,259	26,604	5,966	10	22
Invertebrates	1,232,384	6,161	2,496	0.20	41
Plants	298,506	12,055	8,457	3	70
Others	50,040	18	9	0.02	50
Total	1,642,189	44,838	16,928	1	38

Source: IUCN

Note: An estimated 30% of amphibians and 21% of mammals are threatened by extinction

These numbers are only those species that have been discovered and described, but in addition to these, an enormous number has not yet even been discovered, of which many are going extinct before discovery—at an estimated rate of 50,000–150,000 species per year. It is estimated from fossil analysis and other research that the background extinction rate is about 1 species going extinct per million species per year. If we assume the current number of species to be hundred million, the background extinction rate would be about 100 species per year, so this means that the current rate of extinction is about 1,000 (between 500 and 1,500) times the background rate [4].

4.1.2 Biodiversity and Evolution

The term "biodiversity" first appeared about 1985. It was coined from the term used until then, "biological diversity," the idea that many living things are interacting to maintain the richness and balance of ecosystems.

It is useful to consider three levels—ecosystem, species, and genetic—when defining biodiversity. Diversity at the lowest genetic level, that is, genetic diversity, could be described as diversity within a species, from differences between individuals and differences between populations (Fig. 4.1). To take a human example, this would refer to the differences between individual people and also to differences between groups such as Japanese and Scandinavians. Even within a species, there may be different characteristics caused by genetic differences, such as in the shape and behavior of individuals. Diversity within a given species raises the chances of survival through adaptation, as a species, to environmental change.

Species diversity could be described as diversity among species, and relates to the existence of many species, as already mentioned. Ecosystems are created by the interactions among many species, and thus the extinction of species poses threats to ecosystems.

Ecosystem diversity is the diversity of a system created by the mutual interrelationships of a variety of species. Even the same forest or coral reef will contain many differences resulting from location and environmental conditions, which is why there are so many diverse ecosystems on Earth. Ecosystems are composed of a balance among the many species they contain. Thus, if even only just one species is removed, the overall balance could suffer.

In response to changes in the global environment, at all levels—genetic, species and ecosystem—life has gone through change as it flourishes, declines, and goes extinct—in other words, evolves. For example, in a cold environment, individuals adapted to the cold will have more chances to survive and pass on their cold-resistant DNA to offspring, so that DNA will flourish. On the other hand, some DNA will disappear. This dynamism woven together by genetic diversity at the individual level has ensured species and ecosystem diversity. Genetic diversity, through the process of evolution, connects the past, the present, and the future of life systems.

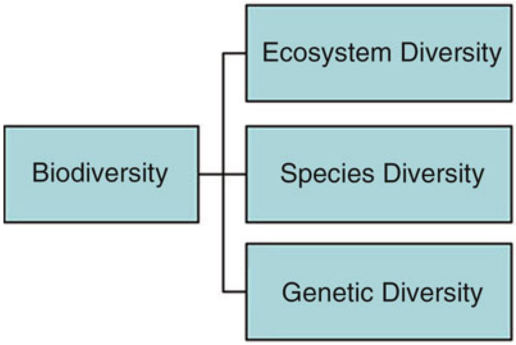

Fig. 4.1 The three levels of biodiversity

4.1.3 The Causes of Mass Extinctions

It is said that five mass extinctions have occurred on the Earth, and this present one is being referred to by some as the sixth mass extinction [3]. The most recent mass extinction event is famous for being the extinction of the dinosaurs 65 million years ago, at the end of the Cetaceous Period in geologic time. In contrast to the past mass extinctions, which are thought to have been caused by natural calamities such as crustal movement, volcanic activity, climate aberrances, and collisions with huge meteors, human activities are the main cause of the mass extinction currently under way, which is referred to as the Holocene extinction event.

Humans have a history of causing extinction of many species by placing pressure on other species through hunting and other activities. Today as well we continue to threaten other species by invading wildlife habitat as a part of "development" activities, and poaching animals for economic gain, for example, to obtain ivory and alligator skins. Conversely, the reduction of certain human activities that sustainably maintained an ecosystem may result in the deterioration of that ecosystem. One example of this process is Japan's *satoyama* (coppice forests near villages), which once flourished but have fallen into disuse [10].

Ecosystems are vulnerable to climate change: warmer atmospheric temperatures are increasing the threat of species extinction. Japan is the home of diverse forest ecosystems, ranging from subtropical to subarctic forests, but if the average temperature rises by 3 °C over the next 100 years as a result of global warming, the current ecosystem distribution will have to migrate about 500 km to higher latitudes, or 500 m higher in altitude. This figure means migrating at 50 km or 50 m per decade, a relatively rapid rate to which plants may not be able to adapt. The rise of atmospheric and seawater temperatures has an especially large impact on mangroves, coral reefs, and alpine species, resulting in more species becoming going extinct.

Also, because of the destruction of the ozone layer, more harmful ultraviolet rays are reaching the Earth's surface, and this is believed to be causing the rapid extinction of amphibians that are vulnerable to ultraviolet rays, such as salamanders and many species of frogs. Chemicals are also causing major problems. Killifish and water striders were often seen in creeks and streams of the Japanese countryside before the country's period of rapid economic growth of the 1960s, but they became a rare sight after the introduction of agricultural chemicals for modern farming. Large numbers of abnormal shellfish with both male and female characteristics have been discovered, affected by manmade chemicals known as endocrine disruptors (also known as environmental hormones) in the environment, which raise concerns about the impacts of these chemicals on the reproduction of species [11].

Exotic species transported by humans into new areas have caused the destruction of endemic ecosystems in many places around the world. One example is in Japan's Lake Biwa, where the endemic species of carp are plummeting in number as a result of the introduction of more aggressive and nonnative black bass fish.

4.1.4 Biodiversity: A Health Indicator for the Global Environment

The current state of biodiversity—facing mass extinction—is sounding a warning bell about human activities. Among the animals, the greatest concern about extinction is for amphibians, which are susceptible to the effects of endocrine disruptors as well as stronger ultraviolet rays as a result of ozone depletion. According to the IUCN (2008), 1,905 species of amphibians (30%) face extinction [9].

Amphibians are the first animals that came onto the land from the oceans. They arrived on land 350 million years ago and survived three mass extinctions, but how will they be affected by the current crisis?

The term "climate canary" was coined in recent years [12]. Miners in the past would carry canaries into coal mines to warn them of the presence of carbon monoxide and other harmful gases, as canaries are more sensitive than humans to toxic gases. That was the origin of the term "canary in a coal mine." Thus, a climate canary would be an animal that is susceptible to the impacts of climate change. In that sense, frogs and other amphibians could be considered the "canaries of global warming."

Humans are members of the global ecological system, and our survival depends on the existence of other species. As the mass extinction of species continues, will it be possible for humans to survive without any disruptions? It would be wiser to see the protection of biodiversity as something closely connected with the future security of humanity. Indeed, the state of not only the amphibians but biodiversity as a whole would be an excellent indicator of the health of the global environment. By maintaining that health, we will be able to continue benefiting from the gifts of nature.

4.2 Free Benefits: Ecosystem Functions and Services

4.2.1 The Value of Genetic Resources

Why is biodiversity so important? Although biologists and ecologists have a good basis to answer that question, there is also a strong answer from the perspective of economics [13–15].

The most direct way to grasp the economic value of biodiversity is through the value of resources such as food and timber. The debate at this level is more about the value of species of rice, wheat, cedar, or cypress, for example, but even within a species there are special traits such as hardiness in certain environments, higher productivity or faster growth. The issue here is the value of individuals that carry the DNA for these traits, which really makes this an issue of the value of the DNA and leads to the commonly-used term "genetic resources."

Recently, genetic resources have attracted special attention in connection with the development of pharmaceutical drugs. Since long ago, humans have used a variety of plants and animals for medicines, as is popularly known with Chinese traditional medicine. Today, however, in the development of new drugs there have been many cases in which researchers extract chemical substances from the plants and animals used by indigenous peoples around the world, investigate the medicinal effects, and then synthesize the substances artificially. A well-known example is the anti-malarial drug quinine, from a substance that was originally extracted from the bark of the cinchona tree and used as an anti-fever agent by indigenous people in South America.

A vast number of species in the world are not yet known to humanity, and many are thought to hold the clues to development of new medicines, but their careless harvesting and the impacts of human activities could lead to their extinction. Biodiversity is richest in tropical forests and such areas, for example, as China's Quinhai and Yunnan provinces, and local indigenous people are becoming increasingly opposed to the monopolization by Western pharmaceutical companies of the profits arising from the development of drugs. Countries have conflicting interests when it comes to access to genetic resources.

4.2.2 Ecosystem Services: Gifts from the Environment

It is easy to appreciate the value of biodiversity as a resource, but besides that, humanity benefits in many ways from biodiversity in ways that we cannot see. Oxygen is created from plant photosynthesis, and the forests of Amazon and other places supply an enormous amount of oxygen to the atmosphere. Forests cover 70% of Japan's land surface. They store in their roots and trunks a huge amount of the rain that falls on them, and they prevent floods and landslides. Forests also help to smooth out extremes of heat and cold, and create a comfortable climate.

Ecosystems are also for humans a source of scenic beauty as well as the other benefits such as spiritual calm, rest, recreation, and amenities. These types of functions of ecosystems are known as ecological services, gifts of nature, and environmental benefits. The loss of biodiversity reduces the functions of ecosystem necessary for all living things, as well as ecosystem services and the resilience of ecosystems to withstand environmental change. Our survival and well-being are dependent upon the ecosystem services we enjoy for free. Indeed, much research has attempted to calculate the monetary value of those services [15].

4.2.3 Biotechnology and Biomimicry

There is growing expectation for the development of biotechnology, such as the manufacturing of food and chemicals using living things, and technologies that use microbes to treat effluent and waste.

Similar to biotechnology is the concept of "biomimicry," the development of new technologies by mimicking and obtaining hints from forms and functions found in nature. Biomimicry is an attempt to be in harmony with nature by copying natural systems as closely as possible.

Volkswagen produced the Beetle, nicknamed after an insect, but Mercedes-Benz recently revealed a concept car that imitates the plump shape of a boxfish swimming in the sea. Even though the car is shaped like a box, which gives it plenty of interior space, it has low wind resistance and excellent fuel efficiency. Hints about harmony with nature are hidden in the shapes of insects, birds, fish, and plants, and in this sense as well, there is value in biodiversity.

4.2.4 A Mirror of Human Society: Animal Society

We are learning more about ourselves by studying societies of other animals, including not only primates such as the chimpanzee and gorilla, closely related to humans, but also a variety of other animals. Primate research is being conducted not only through observation at the behavioral and biological level but also the genetic level, and researchers have found the differences between primates and humans to be much less than originally thought.

The relationships between individuals in troops of the Japanese macaque (snow monkey) are rich with implications about human relationships. Thus, the protection of biodiversity is important also to allow us as humans to learn more about ourselves.

4.3 Protecting Biodiversity

4.3.1 Nature Protection and Biodiversity Conservation

Since the 1970s when the then-unfamiliar term biological diversity first came into use, many different types of work that until then had been referred to as nature protection came together into the concept of biodiversity conservation.

It is worth noting the difference in the meaning of the words "preservation" and "conservation." The former is closer to *protecting nature for nature itself*, while the latter is closer to *protecting nature for humans*. Conservation means preserving biodiversity so that humans may use it: protecting and using. Similar to giving a monetary value to ecosystem services, which allows us to incorporate that value into modern economics, the idea of conservation carries an anthropocentric concept that something should be protected because it can be useful for humans. On the other hand, protection is based on the stance that biodiversity has value in itself; stated more strongly, this means that all life has intrinsic value and should be protected, whether it be the species or the individual.

Just as indicated by these differences in the meaning of terms, acute conflicts often arise in the field and in the world as the consequence of differing intent.

4.3.2 The Convention on Biodiversity

The Convention on Biological Diversity is a comprehensive international treaty on the conservation of biodiversity on a global scale. It was opened for signature at the Earth Summit in Rio de Janeiro in 1992, at the same time as the Framework Convention on Climate Change, and entered into force in 1993. The convention does not specify individual species or particular ecosystems.

The three objectives of the convention can be summed up as follows: (1) conservation of biological diversity together with their habitats, (2) the sustainable use of its components, and (3) the fair and equitable sharing of benefits arising from the utilization of genetic resources.

The "together with their habitats" in the first goal is an important point in this convention. The implication is that it is not enough to simply conserve species in protected areas and zoos. The convention clearly states that it is about the conservation of biodiversity and sustainable use. In addition, in its third objective the convention incorporates the views of developing countries, which strongly advocated for the sharing of the benefits of genetic resources, and recognizes the sovereign right of nations over their natural resources. Some developed countries are dissatisfied with this aspect, as they want the free use of genetic resources from developing countries for their own biotechnology industries and genetic engineering. For this reason, just as with the Framework Convention on Climate Change, the United States has not yet ratified the Convention on Biodiversity (as of June 2012).

In addition to those already mentioned, other international agreements for the protection of nature are listed in Table 4.2. The Cartagena Protocol on Biosafety (under the Convention on Biodiversity) was created to prevent possible negative impacts on the conservation and sustainable use of biodiversity from "living modified organisms" (LMOs)—organisms that have been modified by modern biotechnologies, including genetically modified organisms.

Table 4.2 International agreements on nature conservation and terrestrial living resources

• Antarctic Treaty, Washington, DC, 1959
• World Heritage Convention: Convention Concerning the Protection of the World Cultural and Natural Heritage, Paris, 1972
• Convention on Biological Diversity (CBD), Nairobi, 1992
• Convention on the Conservation of Migratory Species (CMS) of Wild Animals, Bonn, 1979
• Convention on the International Trade in Endangered Species (CITES) of Wild Flora and Fauna, Washington, DC, 1973
• Ramsar Convention: Convention on Wetlands of International Importance, especially as Waterfowl Habitat, Ramsar, 1971
• Convention to Combat Desertification (CCD), Paris, 1994
• FAO International Undertaking on Plant Genetic Resources, Rome, 1983
• International Tropical Timber Agreement (ITTA), Geneva, 1994
• Cartagena Protocol on Biosafety, 2003

4.3.3 The Growing Importance of Biodiversity as Resource

When it comes to resources known as biodiversity, there are clear differences in the stances of developing countries, which have rich genetic resources, and developed countries, which are interested in using them. This is the basis of a confrontational framework between countries that have the resources and countries which have the technologies.

Although developing countries are host to rich genetic resources, until now in many cases only the developed countries benefited from them, so some developing countries assert that they have not received adequate compensation. Developing countries are aware that medicinal herbs and other materials have been used as genetic resources, and viewing this as "indigenous knowledge" or "local knowledge," they have begun to demand the protection of intellectual property rights of such knowledge more strongly than before.

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Chapter 5
An Evolutionary View of the Environment

5.1 How Should We View the Changing World?

5.1.1 Laws of Change

Even though we may claim to have superior intelligence, humans are only one species that happened to appear on this planet we call Earth, and we are not above the laws of evolution. With our powerful weapons of technology, however, we do have some capacity to dominate the environment. Nevertheless, that capacity is not all powerful.

It often happens that when we do something we believe will solve one problem, a negative outcome occurs through a chain of reactions. The difficult thing about discussing the effects of human behavior on the environment is predicting these chain reactions. The world we live in is made up of both orderly behavior on larger trends and random variability. One good example of this point is a comparison of changes in the global climate and the weather. Besides the changes over the four seasons, there are also changes in temperature from day to day, as well as changes within each day. Just when it seems that good weather has continued for a while, suddenly we may experience a severe storm or cold snap. There are also large waves of climate change that occur in cycles with timescales ranging from a few 100 years to tens of thousands or millions of years.

The climate system is a good example of a complex system that we also happen to experience in our daily lives [1–5]. Even though good weather may continue for some time, it is absolutely certain that the rain will fall again 1 day, although it is quite difficult to accurately predict when that day will come. In Japan we know that typhoons will occur when the season changes from summer to autumn each year, but it is very difficult to predict exactly when one will occur and which path it will take. Prediction is difficult for complex systems, but there are certain laws of change that they share in common, and we consider these now.

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5.1.2 Limits to Growth: Goats on a Deserted Island

With an abundance of food and an absence of predators, the number of individuals of a species will increase exponentially—this is true whether it be humans, wildlife, or microbes. In the real world, however, the amount of available food and space is limited, so the maximum number of individuals has a certain limit. In such cases, a logistic curve is helpful to explain changes in the numbers of individuals. With a logistic curve, the number of individuals grows exponentially when the number is small, but as the number increases, the growth rate declines and asymptotically approaches a limit. This curve resembles an elongated letter "S" tipped to one side and is commonly called the sigmoid curve (Fig. 5.1) [6, 7].

Besides being applied to human populations, the logistic curve is also used for predicting annual sales of products such as automobiles, home appliances, and cell phones. In the case of television, the market was saturated when every household had a black-and-white television, but this was repeated again when each new product came onto the market—such as the color television, the thin-screen television, and so on. Figure 5.2 shows several superimposed logistic curves.

An important point about the logistic curve is that as the number of individuals approaches saturation, the growth rate slows down. Here, the mechanism that causes this effect is a key factor. In the case of domesticated animals, things are fine if humans manage the numbers, but if left up to nature they are likely to eat until they run out of food. The Ogasawara Islands off the coast of Japan are a group of remote islands rich in biodiversity. People introduced goats to these islands for their meat, but some escaped into the wild and multiplied out of control. They ate plants right to their roots, pushing even rare plants to the brink of extinction. Efforts are now underway to exterminate the goat from the island.

In the case of manufactured products, if the market becomes saturated, there is no way to increase sales other than through the introduction of appealing new products attractive to consumers. Manufacturers that fail to properly manage such a situation could end up driving each other bankrupt through price wars.

5.1.3 The Lion or the Deer: Which Is Strongest?

We are told that dinosaurs once ruled the Earth. But what does it really mean to be the dominant species? Dinosaurs were the best adapted to the conditions of the global environment in that era. Species that are unable to adapt to major environmental changes cannot avoid extinction, regardless of how they may have flourished previously. Environmental change could come from external factors of cataclysmic proportions, or they could come from mutual interactions between species. The former might include a collision with a large meteor, tectonic activity, volcanic eruptions, tsunamis, floods, and so on. Regarding species interactions, the example of the lion and the deer as a model in mathematical biology is ripe with meaning.

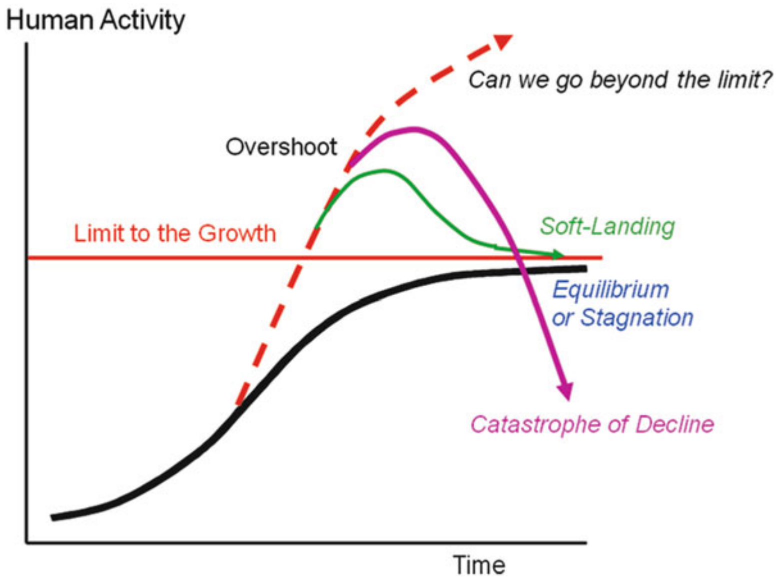

Fig. 5.1 Logistic model. The magnitude of human activity may stabilize if it approaches the limit slowly. However, if human activity continues to grow far beyond the limit, then an overshoot may take place, leading to a catastrophic decline

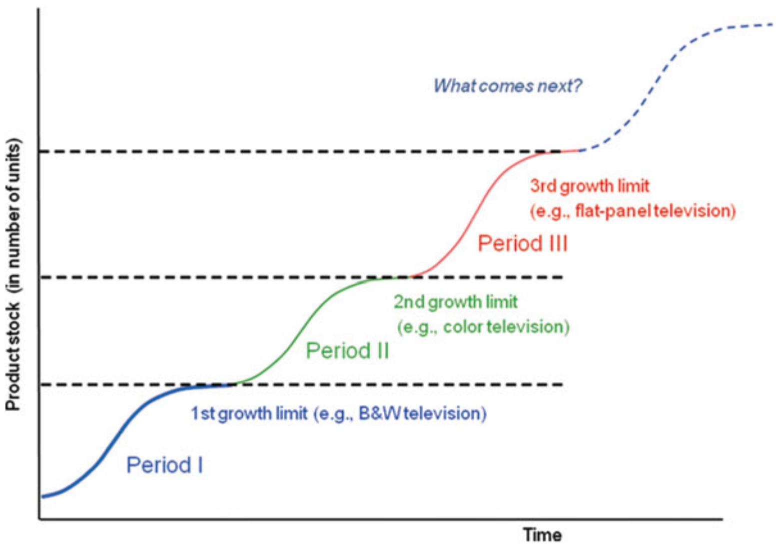

Fig. 5.2 Multistage logistic model: cycles of new product development. When existing technology saturates the market, the growth rate flattens, but then a new technology cycle begins

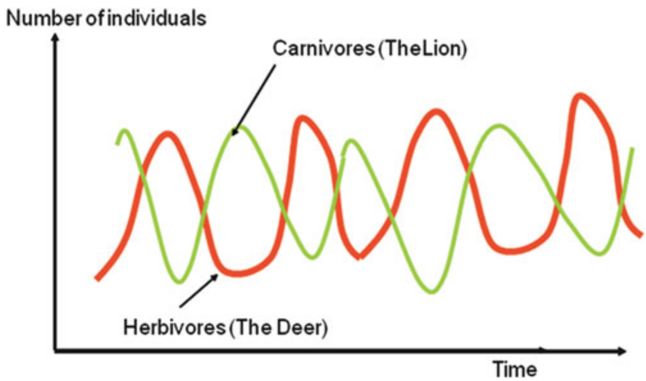

Fig. 5.3 Limit cycles of two species. The strong (e.g., the lion, a carnivore) and the weak (e.g., the deer, a herbivore) are actually mutually dependent. Their numbers go through oscillating cycles of flourishing and declining

If there is an abundant deer population, lions will prey upon them and multiply. If they do so, the lions will run out of deer to eat and start to die of starvation. Eventually, the deer will begin to multiply, and again the lions will begin to increase. Through such a framework, the number of lions and deer will increase and decrease repeatedly in what is known as a "limit cycle," as illustrated in Fig. 5.3 [8, 9].

This model is useful to understand phenomena in which two or more entities mutually interact. Similar cycles can be observed with the numbers of crimes and police, the spread of communicable diseases, and the supply and demand of products. If the number of crimes increases, the city increases the police force, but then crimes decrease, so the police force is reduced, in an ongoing cycle. Epidemics also behave this way. After large numbers of people have caught the disease and died a virus can find no new hosts, so at one point the disease stops spreading, but later it begins to spread again.

The nuance of this model is that it is difficult to tell which is strong and which is weak—the lion or the deer. If too successful at hunting, the fate of the "strong" lion will actually be determined by the "weak" deer.

5.1.4 Paradigm Shift: From Caterpillar to Butterfly

In nature, besides changes in population numbers, there are also changes of state or phase. For example, water changes from solid state to liquid and then to gas in what is known as phase transitions. The transformation of a caterpillar into a chrysalis and then a butterfly is also a fascinating example of transformation (Fig. 5.4).

Fig. 5.4 An example of transformation. *Source of pictures*: http://www.creationism.org/japanese/monarch_ja.htm

In the human world there are transformations of political regimes (e.g., revolutions, transfers of power by political parties) and economic systems (e.g., from socialism to a market economy). One feature of these transitions is the sudden change that occurs at the turning point. Major changes in governments as a result of elections are often referred to as paradigm shifts, as are revolutions of political systems.

Many phase transitions occur in the natural world. Examples include the phase changes from ice into water then water vapor, the magnetization of metal, and the superconductivity of liquid helium. When ice changes phase to become water, heat applied from an external source makes the water molecules move more rapidly by thermal motion. The binding between molecules weakens, and at a certain point, a transition occurs. In human society as well, there are cases when individuals in a group are together and associated, then suddenly separate. With environmental problems as well, it often happens that rapid changes occur in society when something suddenly triggers a wave of public attention on an issue in which people initially may have had no interest.

5.2 Earth from the Thermodynamic Perspective

5.2.1 Order, Disorder, and Entropy

In recent years, the term entropy has appeared often in debates about energy issues, resource recycling, life, ecosystems, and sustainability [10, 11]. It is not a purpose of this chapter to expound on entropy at length, but there are a few valuable points to be made for this discussion. The concept of entropy can be useful to understand the core essence of certain economic and environmental problems [12, 13]. To understand nature and human society, it is certainly useful to use the entropy concept, which originates from physics, but we must be aware that there are limits to its application for these issues. The term may give the impression of being profound, but because it is certainly not easy to understand the concept correctly, there is a risk that people may fail to make a critical analysis.

Explained in terms of statistical probability, entropy is a measure of the state of randomness. Go is an ancient strategic board game for two players, played with black and white stones. If there are two piles of Go stones, one pile white and the other black, a slight knock will make the piles collapse, mixing the two colors of stones. By an increase in the randomness of the system, entropy has increased. But no matter how long you wait, the mixed stones will not on their own separate themselves into black and white again. If there were only a few stones of each color, by coincidence they might separate that way, but if there were 100 or 1,000 of them, it would simply not occur.

The inside of a room tends to become messy, but a messy room will not create order on its own. Sugar water and salt water may mix, but there is no way that a mixed solution will separate itself again into sugar water and salt water. These are metaphors for the law of increasing entropy. An increase of entropy means that order over time transforms itself into a state of disorder. For example, an animal carcass or dead plant returns back to the soil, a product deteriorates and becomes waste and ends up in pieces—all these examples are in line with the law of increasing entropy [14, 15]. When ice melts to become water and water vaporizes, the bonding between water molecules weakens and randomness increases; these are phase transitions in the direction of greater entropy.

Because the explanation of entropy relates to resources and energy, we defer that discussion to Chap. 9. It is important to note, however, that the explanation of Go pieces is simply an illustrative example, different from the thermodynamic entropy. Information entropy is also different from thermodynamic entropy. It is important to be aware that there are differences between entropy of physical quantities such as energy and temperature (thermodynamic entropy) and entropy as a metaphorical concept for states of randomness or disorder [16].

5.2.2 Steady-State Open Systems and the Earth

The foregoing is a rather dated discussion about entropy, describing a state of equilibrium in a closed system that has no external material exchange outside the system. In the latter half of the twentieth century, thermodynamics began to target open systems with external energy and material exchange in systems that were not in equilibrium—the *thermodynamics of irreversible processes*. This breakthrough was the achievement of Ilya Prigogine, laureate for the Nobel Prize in Chemistry in 1977 [5].

The theory developed by Prigogine and his co-workers defined the amount of entropy production and proposed that entropy production become minimal in a steady-state open system in a state of nonequilibrium. If a low gas flame heats water in a kettle, the heat from the gas flame reaches a balance with the heat escaping from the surface of the kettle, and the temperature becomes stable. If you put sawdust into the kettle at this point, you can see convection occurring in the kettle. Such a system, maintaining a certain state (structure) while exchanging energy and material with the environment, is called a steady-state open system [1, 2]. Large-scale ocean circulation is also a steady-state open system on the Earth. The human body is also a steady-state open system that uses food as an energy source, maintains cell metabolism, and maintains body temperature at about 36°C through regulatory functions of perspiration and so on. The term "homeostasis" is used to describe the property of a system to regulates its internal environment and maintain a stable condition.

Living things constantly take in material from the outside world, metabolize it, and then emit waste back to the outside world: this is none other than a steady-state open system in nonequilibrium. Prigogine and his co-workers studied special cases of spatial patterns and cyclical phenomena for various systems, including material diffusion, thermal diffusion, chemical reactions, and electrochemical reactions. Their research did not reach the point of explaining complex things such as biological phenomena, but their work was significant for being extremely rich with implications for further thought. They gave us a glimmer of light to help understand life forms and ecosystems [15, 16].

5.2.3 Material Circulation and Entropy in Nature

Life creates order from disorder. Organisms, humans included, obtain the energy necessary to sustain life through physicochemical transformations to material taken in from external sources, and sustain that activity while creating new material. Starch when metabolized converts easily into carbon dioxide and water, resulting in an increase in entropy. The reverse reaction does not easily occur. Living things, however, accomplish this effortlessly.

Plants, through photosynthesis, create carbohydrates (sucrose, glucose, starch, etc.) from water and carbon dioxide in the air, and it is clear that they are reducing entropy—even if we just consider the process in which they select and take in sparsely distributed carbon dioxide molecules from the air. Animals, through chemical reactions aided by a variety of enzymes, are able to digest food, synthesize proteins, and perform work through their muscles. Life forms maintain the order in their own selves, going against the law of increasing entropy by the workings of vitamins, hormones, enzymes and other chemicals, incorporating complex genetic information, and so on.

To sustain their lives, living things synthesize complex chemicals (starch, sugars, amino acids, proteins, enzymes, vitamins, etc.) from simply structured molecules such as CO_2 and H_2O, create living tissue, and keep their internal systems functioning. All this is nothing short of truly amazing. These workings of living things create internal programs that seem to be designed for the very purpose of sustaining the organism's own life and are engaged in self-organization to achieve that purpose. This capability of living organisms is the capacity to create order, which functions to decrease entropy.

This function of life to reduce entropy may seem to contradict the second law of thermodynamics which states that entropy in the universe increases over time, but that law applies to closed systems, which have no exchange of energy or material with the outside world. In contrast, the Earth is an open system that receives solar energy from outside. It is thanks to solar energy that plants can reduce entropy through photosynthesis.

The foregoing discussion is about biological functions at the cellular or individual level, but it is worth noting that all living things on Earth together make up an ecological system. Within this ecological system, living things both eat and are eaten, and material circulates within this cycle of the food chain. Within this material circulation, it is essential to have both primary producers that conduct photosynthesis and decomposers which decompose organic matter such as animal waste and carcasses.

Material circulation on the global ecological system could be broadly described as being composed of the functions of both primary producers that reduce entropy and decomposers which increase entropy. Although solar energy is necessary for the basic producers, heat is generated in the decomposition processes: this heat is emitted into space through atmospheric circulation.

5.2.4 Human Activity and Entropy

A child was handed a bottle containing a mixture of sugar and salt and ordered to separate the sugar and salt before the next morning, but an army of ants came along and helped by separating out only the sugar. This is from a children's story the author heard once, but let us examine it more closely. A mixture of sugar and salt is in a high state of entropy, but if sugar is only with sugar and salt only with salt, the situation is in a low state of entropy. Seen this way, the task for the ants in the story was to work hard to reduce the entropy of the mixture.

Bees fly all day from flower to flower, collecting nectar to produce honey. We are told that bees need millions of flights to produce 1 kg of honey. In the city of Nagoya, with a population of 2.2 million people, garbage is collected twice a week. It is labor-intensive work to collect thousands of bags each round. A mixed pile of black Go stones and white Go stones can also be sorted through the work of humans. If we see the task of collecting and sorting scattered items as actually reducing entropy, then human labor or physical work can be seen as providing energy and at the same time reducing entropy. In this kind of debate, the concept of entropy is useful, but as stated earlier, entropy here differs from the entropy of thermodynamics. Thermodynamic entropy is related to the randomness of positions and velocities of an astronomical number of atoms and molecules—a number of the order of the Avogadro constant (6×10^{23}). Sugar and salt grains, when in solid state, are big enough to be seen by using a magnifying glass, and in one view there might be somewhere of the order of about 1,000 visible grains. In this case, even if sugar *grains* are mixed with salt *grains*, there is little change in thermodynamic entropy. If *solutions* of salt and sugar are mixed, however, there is a change in the entropy, because this is a mixture at the molecular level. In the case of a mixture of black and white Go pieces, the difference in black and white color is not a difference in physico-chemical properties; in this case, the entropy of this mixture would be best seen as information entropy.

That was somewhat of a digression, but even though those examples differ from thermodynamic entropy, the concept of entropy is useful when considering the degree of randomness and order in a system. In the various systems with which we are concerned, it is a statistical and probabilistic reality that there is a tendency to go from order to disorder, whereas living things—at both the molecular and the macro level—act to create order from disorder and randomness.

5.2.5 Environmental Issues and Entropy

When we consider environmental issues from the perspective of entropy, we must look at the metabolisms of material transformation behind environmental phenomena, and the accompanying transfers of energy and heat. There are three major topics to consider here.

First is the issue of efficiency of energy use. The use of energy—whether it be fossil fuel, nuclear power, or whatever—inevitably generates heat, but there are limits to the amount of heat that can be used effectively. A vast amount of energy is present in the environment in the form of heat, but there are constraints on how it can be used effectively. On that point, energy consists of "usable energy" and "unusable energy", and an "increase of entropy" is a "decrease of the amount of usable energy" or an "increase of the amount of unusable energy." In other words, this is a "deterioration in the quality of energy." These points are discussed again in Chap. 9.

The second topic is the issue of resource recycling as an issue of deterioration in the quality of resources. The process of extracting ore from the below the ground and refining it into high-purity metals means transforming entropy from a high state to a low state. Mixing used resources means increasing the entropy that someone had gone to the trouble of reducing. The emission of chemical substances into the environment is also a behavior that increases entropy. Diffusion of pollutants in the environment and mixing of used resources are the changes that increase entropy, and we may define a low entropy state as a desirable condition [11]. The result might be a value system with a preference for behavior that does not increase entropy. This example is just one possible type of value system; in itself, entropy has no ethical significance.

The third topic to consider is the dynamics of the global ecological system—including biological systems, through the prism of entropy theory. This discussion is based on thermodynamics in a steady-state open system, as described above. Discussions in entropy economics are wide ranging, but some thinkers assert that the energy use and material circulation under current models of industrial production are not compatible with the global ecosystem that sustains life; in other words, not in harmony with the natural world's inherent functions and capacity relating to material circulation. If we were to take this argument further, the ultimate model for a society with sound material cycles would be something like Edo-period Japan, for example, as its economy was based upon agriculture, forestry, and fisheries activities that were compatible with material circulation in the natural world. Many conflicting opinions can be expressed on these topics, but it is certainly worthwhile to consider the perspective of thermodynamics when analyzing the life-supporting structure of the global ecosystem.

5.2.6 The Earth as a Heat Engine

The temperature near the equator on the surface of the moon rises to 120°C in the lunar afternoon and drops to minus 70°C at night. This is a huge daily variation. This temperature variation is repeated every day (1 lunar day is equivalent to 1 month on Earth). The Earth also has temperature variations between day and night, but these are not as extreme as on the moon. The reason for the Earth's more moderate temperature changes is that it has both atmospheric and water circulation.

On the moon, the incoming energy from the sun heats the moon's surface, and then escapes from the heated moon surface directly into space. In contrast, about 30% of the energy coming to the Earth escapes back into space by reflection from surfaces including snow and ice cover and clouds, but the remaining energy warms the Earth's surface, atmosphere, and water, which then drive atmospheric convection and water evaporation.

This atmospheric circulation on the Earth resembles the operation of a heat engine. Air conditioners collect heat inside a room and release it outside by using an electrical compressor to repeat a cycle of compressing and liquefying a refrigerant and then expanding and vaporizing it again. The Earth, similarly, releases heat from its surface into space, through cycles of water evaporation and precipitation. Air warmed at the Earth's surface rises, but as it rises, the temperature of the air drops by adiabatic expansion. The air that has cooled at a higher altitude sinks because it is heavy, whereas the temperature of the air rises in response to adiabatic compression. The warming of a strong wind as it blows down a mountain is exactly the same, known as the Foehn phenomenon.

If we look only at the balance of energy entering and leaving the Earth, the law of energy conservation (the first law of thermodynamics) is preserved. On this point, everything is the same as on the moon. It is not possible, however, for life to exist under such extreme temperature variations as on the moon. What differs from the moon is that the energy the Earth receives from the sun is transformed into thermal energy in the air and water, and the circulation of atmosphere and water thereby maintains a relatively constant air temperature. Furthermore, solar energy is used by plants in photosynthesis and linked with material circulation in ecosystems through the food chain. This description shows that to understand the dynamics of the global ecosystem, it is necessary to use concepts of thermodynamics in a steady-state open system. Entropy increases because of the steady generation of waste from life processes in the global ecosystem. By transferring energy from the Earth into space, the internal buildup of entropy is prevented and material circulation is established. This line of thought offers new insight to understanding the global ecosystem

Despite recent progress, the field of thermodynamics for open steady-state systems is still in the process of development, so many inferences and analogies are still needed for us to understand the global ecosystem. There is no doubt that human activities are causing enormous impacts on and changes to the global ecosystem and material circulation, but there are still no answers about how much of this can be tolerated, and it is unclear how far entropy theory can go beyond general discussions to provide quantitative answers.

5.2.7 Is Global Warming Real?: The Role of Water and Water Vapor

It is a fact that average global temperatures have been rising, based on 150 years of data. Some debate still remains, however, as to whether the warming is happening because of greenhouse gases in the atmosphere, and whether the warming trend will continue. Let us consider these issues briefly here.

The reason you feel heat when you hold your hand near a charcoal fire is that heat is radiated from the charcoal fire, but this heat is actually electromagnetic radiation. Sunlight also feels warm because it is electromagnetic radiation from the sun. But even though both are electromagnetic waves, the electromagnetic radiation emitted from high-temperature bodies such as the sun has a relatively larger component of short wavelengths, whereas the radiation from a low-temperature body has a relatively larger component of long wavelengths.

A charcoal fire, when fanned, will burn more strongly and the flame color will turn from red to orange. In the late 1800s the German steel industry was flourishing as a result of the Industrial Revolution. The color and temperature of industrial blast furnaces was therefore an important technical matter, so researchers began to study the relationship between temperature and the wavelength spectrum of electromagnetic waves emitted from heated objects. It was Max Planck who reached some conclusions and developed the famous formula now known as Planck's law. It is well-known that his work led to the birth of quantum mechanics at the beginning of the twentieth century.

Planck's law tells us that most of the light coming from the sun, with an absolute surface temperature of radiation of 6,000 K contains electromagnetic radiation with a wavelength of about 0.5 μm, whereas a body at about human body temperature (absolute temperature about 300 K) contains mostly infrared radiation at a wavelength of about 10 μm. The star Sirius is bluish in color, and this is because it is hotter than our sun and its radiation contains a larger component of shorter wavelengths. Infrared rays are emitted from the Earth's land and sea surfaces that have been warmed by incoming energy from the sun, but greenhouse gases such as carbon dioxide have properties by which they absorb this infrared radiation. The absorbed energy is converted into kinetic energy in molecules of carbon dioxide and other gases, and this warms the air. In the end, however, the heat accumulated in the air ultimately escapes to space from the upper limits of the atmosphere. Whether or not greenhouse gases are present, the total amount of energy that enters the Earth's atmosphere from the sun and the total amount of energy that escapes into space from the Earth's atmosphere are the same. This situation closely resembles the steady state mentioned earlier when heating a kettle of water with a low gas flame.

The greenhouse effect caused by carbon dioxide is also similar to a person wearing clothes for protection from the cold. It is thanks to the "clothing" of greenhouse gases that the atmosphere is maintained at temperatures comfortable enough for humans to live in, but if we wear heavy clothing, we will become hot and start to perspire. At this point, it is important to mention the functions of water and moisture relating to the global climate. Actually, water vapor (H_2O) causes a greenhouse effect exactly as do carbon dioxide and methane, and in fact water vapor is more potent than these gases are and accounts for more than 60% of the greenhouse effect in the global climate. Furthermore, water plays a major role in the global climate in many other ways—through snow and ice cover, the evaporation of water, cloud formation, precipitation, large-scale ocean circulation, and so on. Snow and ice cover directly reflect solar rays and prevent the Earth from warming up, water evaporation plays the role of carrying heat from near the Earth's surface up into the atmosphere, and an increase of cloud cover would prevent solar radiation from reaching the Earth's surface.

But even though water vapor has a strong greenhouse effect, the reason that it has not attracted much attention as a major cause of the currently observed warming is that, unlike other greenhouse gases, it is not the result of anthropogenic emissions. On the other hand, the atmospheric concentrations of carbon dioxide, methane, and other gases are rising along with the level of human activities, so their emission trends and warming trends are correlated. These are the reasons that those gases are seen as the causes of warming.

If we look closely, there is certainly some room to challenge the decision to blame global warming on anthropogenic emissions of carbon dioxide and other gases, but we must not forget that if the planet warms up and the amount of evaporation increases, snow and ice cover will decline and the warming will accelerate further.

In contrast to warming, factors that cause global climate to cool include volcanic eruptions and air pollution. There have been times in history when volcanic ashes have remained in the atmosphere for some time, blocking the sun's rays and causing climate cooling to occur. Similarly, particulate matter (aerosols) from coal burning has a cooling effect on the climate, as is also true of an increase in cloud cover.

Climate change has occurred in the past without anthropogenic causes, and some factors other than anthropogenic ones—water and water vapor, for example—may be having a major effect on the warming currently underway. Nevertheless, humans are also causing other changes in hydrological cycles, through forest logging, water resource exploitation, and modifying the Earth's surface with cities and roads.

Global warming is something that must be considered not simply in terms of the emissions of carbon dioxide and other gases but in the context of the whole range of human activities.

5.2.8 Forests and Seas

The discussion jumps a bit here, but let us now consider another example of material circulation in the natural world.

In 1988, fishers along the Nishibetsu River in eastern Hokkaido launched a tree-planting campaign to increase the number of fish, and this movement has now spread nationwide in Japan. But why is it fishermen who are planting trees? In the past, fishers were able to catch many salmon in this river, but the fish population had plummeted. It occurred to them that the reason for the decline was that forests in riparian zones and other areas had been lost because of land development for dairy farms.

In the living world, material circulation works through the food chain. Various nutrients are needed for organisms to grow, and these nutrients are absorbed from the soil by plant roots, circulate through many living things via the food chain, and again are returned to the soil after being decomposed by microorganisms in the soil. Because rain falls onto the land, however, many nutrients are washed from the soil into rivers and carried to the sea. If this continues for a long time, the soil must eventually be depleted of nutrients. This does not occur, however, because of a reverse flow of nutrients. For example, seabirds catch and eat fish, and the nutrients are carried by bird droppings from the sea back to the land. Salmon and trout swim back up rivers to spawn, after which their carcasses also return nutrients to the land. Nutrient cycles such as these sustain biological phenomena on Earth.

The human practice of taking fish such as sardines and herring and using them as fertilizer is also based on the notion of returning nutrients from the ocean to the land. The use of chemical fertilizers leads to nutrients being washed out to sea, causing eutrophication and problems such as algal blooms, which occurs because the natural nutrient cycle has been disrupted. Marine ecosystems need primary producers that grow through photosynthesis, such as phytoplankton, *wakame,* and kelp seaweed. To grow, they need nutrients such as phosphorus and nitrogen, but they cannot absorb those elements unless they also have iron present. The iron that organisms can absorb must be in the form of ferric ions; if the iron is in the form of iron oxide they cannot absorb it.

In a thick forest, so much humus accumulates on the forest floor that oxygen cannot reach it. Here the fallen leaves are decomposed by bacteria and other organisms, producing organic matter. This organic matter reacts and interacts with a variety of other materials, forming fulvic acid, which is water soluble. This fulvic acid and the associated fulvic acid iron are soluble in water, without becoming iron oxides. This fulvic acid iron flows in the river out to the sea and is involved in biological production in the sea water.

The tree-planting activities in Japan, mentioned above, are actually working to restore the nutrient cycle as a part of the material circulation that is so important for the global ecosystem. This is an example of the forests sustaining the oceans.

5.2.9 Humans: Small Size, Big Impact

The global ecological system is a complex system created through interactions between a constantly-changing climate and biodiversity. By the ways in which they adapt to these changes, other changes occur at the genetic level, by which the special characteristics of life forms either develop or disappear, with the result being evolution. There is neither good nor bad in evolution caused by the forces of the natural world, but human activities are having enormous impacts on the processes of evolution. We must be reminded, however, of the metaphor of the lions, which may seem to be dominant but will die out if they eat all the deer upon which they prey.

We do not know if we humans will end up as a fleeting presence on a page in the history of evolution in the global ecological system, but we are a dangerous presence that is risking a destructive knockout blow to the other species that make up the biological diversity sharing Spaceship Earth with us. It is extremely difficult to predict the future of the Earth, which bears the features of a complex system. In fact it is truly impossible to predict. As with the Earth's climate, it is certain that warm and cold periods will continue to come and go, but long-term cycles last millions or hundreds of thousands of years and short-term cycles last hundreds of years, making it difficult to accurately predict the effects of interactions between the rhythms of nature and the impacts of human behavior. Nevertheless, it appears certain that, whatever the cause, the Earth will become warmer during the twenty-first century.

Can it be that only humans, with their advanced intelligence, can be completely free from the laws of evolution? Is the very existence of humans with our capabilities and traits the inevitable product of evolution? Or is this all just coincidence? These are interesting questions to ponder.

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Chapter 6
Transforming Our Society: Low Carbon, Coexistence with Nature, and Sound Material Cycle

6.1 Earth History, Human History

6.1.1 *An Instant in Time*

When our human ancestors still lived only in Africa, the population was apparently only about 100,000. This figure is estimated from current numbers of chimpanzees and other anthropoid apes. Ten thousand years ago, when the Earth began to warm up at the end of the last Ice Age, humans adapted to the changing global environment and began to engage in settled cultivation. Five thousand to six thousand years before the present day, humans began to live together in settlements and urban civilizations developed in the basins of the Nile and Yellow Rivers. In ancient Egypt and the Xia, Yin, and Shang dynasties in China, populations grew to a few million people, and the world's total human population is estimated to have exceeded ten million. At their peaks about 2000 years ago, the populations of the Roman Empire [1] and the Han Empire both exceeded 50 million, and the estimated total world population was 200–300 million, including large populations in what are now India and Mexico. The human population first exceeded one billion in about 1800. In 2012, our population exceeded seven billion.

Humans dominate the Earth today. But it was only 250 years ago, after the Industrial Revolution, that we were first able to exert such control through our science and technology. A scant 10,000 years have passed since humans first began settled cultivation. Will the modern civilization that we currently take for granted turn out to be nothing but the momentary blossoming of a flower in the long history of the Earth?

6.1.2 *Economy and Ecology*

In recent years, the term "eco" has come into common use as an alternative for "environment." Its recent use comes from the English word "ecology." "Economics"

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also begins with the same “eco.” The origin of “eco” is the ancient Greek word *oikos*, which originally meant household, house, or family. How could it be that both “economy” and “ecology” come from the same roots?

Modern society has corporations and a great variety of other organizational structures, but in ancient Greece, where farming and raising livestock were the core productive activities, the *oikos* (family) was the basic unit of society. Families had a master, family members, and slaves, and possessed a certain amount of farmland and grazing land. They were almost completely self-sufficient, running on solar energy [2]. The size of the grain harvest and number of animals were determined by factors such as the amount of land owned, amount of sunshine, temperature, and rainfall.

Imagining the situation of families in ancient Greece, we can understand now how both economy and ecology can have the same origin. Economy had to do with managing the family on the earnings from farm produce harvested and sold. The word “economics” has similar origins, associated with the home economics of managing the family income and expenditures. On the other hand, “ecology” was concerned with the natural conditions that determined how much income could be earned, including the size of crops to plant and how many livestock to raise.

6.1.3 Closed Economy, Open Economy

An economy based on agriculture and livestock and mostly affected by the blessings of the heavens and earth is what economist Kenneth E. Boulding referred to as a closed economy [3]. This is an economy that operates within relatively small regional confines and does not engage in much interregional trade. In ancient Greece, all necessities—clothing, food, housing, etc.—were obtained from the harvests from nature, and all waste had to return to nature. During that era, economy and ecology were basically the same thing.

The separation of the two “ecos” came with the birth of the modern industrial civilization, as a result of the Industrial Revolution at the end of the eighteenth century. Motive power before the Industrial Revolution came from human and animal power. The fastest transport was the speed of a horse running. After the Industrial Revolution, humanity had at its disposal unprecedented power and speed, through the use of steam engines and, eventually, internal combustion engines. As a result, humanity was able to excavate and exploit on a vast scale buried resources such as fossil fuels, metals, and minerals, and to use them as if their supply was endless. This was the beginning of the “open economy,” or cowboy economy, as Boulding called it. Eventually, huge amounts of commodities could be carried enormous distances, by rail, ship, automobile, or airplane.

It was fossil fuels that sustained the Industrial Revolution. About 100 years after the start of the Industrial Revolution in England—by the end of the nineteenth century—steel was being used abundantly in Europe and America. In 1853, an American navy fleet, known in Japan as the Kurobune, or Black Ships, appeared offshore of Edo and eventually compelled Japan to open to the West. Those ships were clad in iron, making them appear black. The first transcontinental railroad opened in 1869 in the United States, and the Eiffel Tower, with its monumental structure made of iron, was completed in 1889 for the World Exposition in Paris. In Europe, at the end of the nineteenth century, architecture and decorative art often used iron as a material for what was known as Art Nouveau. The First World War was a conflict that consumed huge amounts of iron in guns, canons, cannonballs and warships.

The model of industrialization based on coal and iron is still alive and well today in the twenty-first century. China is a good example of this. After the Second World War, China experimented with nation building under a communist regime using socialism. The philosophy of Mao Tse-tung put an emphasis on agriculture, farmers, and farm villages, and in the sense that he attempted to achieve economic development by using only resources within the country rather than depending on the outside. His philosophy was one of a closed economy. This experiment failed, however, and from 1979 onward under the leadership of Deng Xiaoping, the country shifted toward an open policy. In terms of economic openness, China also moved toward an open economy in terms of resource use. The consumption of coal and iron increased rapidly. Annual iron production in China during the 1950s was about five million tons. By 2007, production had risen to 2.6 billion tons of coal and 500 million tons of iron. In a way, this all makes sense if we realize that China is now achieving its own delayed Industrial Revolution.

6.1.4 Agricultural Civilization

Archaeologists have made many interesting discoveries about where and when agriculture first began. It is said that the cultivation of wheat and barley began about 9000 BC in the region around present-day Palestine. This cultivation was propagated to Egypt and Mesopotamia, where large-scale irrigated farming began in the river basins of the Nile, Tigris, and Euphrates. There are several theories about the exact timing, but it seems that this likely occurred about 5000 BC. Agriculture also began along the Yellow River and Yangtze River in China. Evidence suggests that wheat cultivation arrived in northern China from Mesopotamia via Central Asia, whereas rice cultivation came to southern China via a different route.

Large-scale irrigated agriculture made it possible to produce and store large amounts of grain. Agriculture produced large surpluses, which freed people from having to dedicate their days completely to obtaining food and allowed them to produce goods such as pottery and bronze, and this led to the building of civilizations. It is possible that climate change after the end of the last Ice Age caused the extinction of the animals that humans hunted, so they ceased their nomadic roaming and had to cope with the new problem of securing food. It is also possible that under the new environmental conditions, humans discovered wild grains, millet, and leguminous plants, and began to cultivate them. In Japan, traces have been found at the

Sannai-Maruyama site in Aomori Prefecture indicating that the people cultivated chestnut trees during the Jomon period. Discoveries such as these have been made through research into pollen buried in ancient ground layers.

The conversion of grasslands to cultivated land and the creation of water courses for irrigation marked the beginning of human activities that alter and manage nature. It has never exactly been easy, however, for humans to manage nature. The water that was so essential for agriculture was controlled by natural conditions such as sunshine and precipitation. Lack of rain would mean a drought; too much rain, however, the fields would be washed away by flooding.

If irrigated farming continues for long, ground salt dissolves in the water and then is deposited on the ground surface. In a country of abundant rainfall such as Japan, the salt is washed away by the rain, but in arid regions like Central Asia, it gradually builds up on the ground surface, eventually making the land unsuitable for agriculture: this is referred to as salinization of soil. One theory suggests that the ancient Mesopotamian and Indus Valley civilizations collapsed as a result of soil salinization, which was caused by irrigated farming over many years.

The productivity of an agricultural civilization is strongly influenced by the area of land that can be used as farmland and by the productivity of the land. And land productivity is determined by such factors as the nutrients in the soil, natural conditions such as hours of sunlight and amount of precipitation, the use of farm implements such as hoes and harrows, irrigation infrastructure, and farming methods. In any case, because agriculture was the source of production, the crop sizes were largely affected by climate conditions. This situation is exactly the same as for agriculture nowadays [4]. Today, however, recombinant DNA technology makes it possible to use selectively pest-resistant and climate-resilient crops that produce high yields.

6.1.5 Links Between Climate and the Industrial Revolution

During the Medieval Warm Period, the Vikings of Scandinavia became active and discovered Greenland and the American continent. The cooling of the climate during the Little Ice Age was a huge blow to agriculture. Also, in China and surrounding areas, climate change forced northern nomads to descend southward in response to a lack of feed grass for their animals, and this had a major impact on Chinese history and dynastic change.

There is an argument that the cooler climate of the modern Little Ice Age was a trigger for the Industrial Revolution. In England and other European countries, wood fuel was needed for warmth in the cooler climate conditions, which led to the clearing of their forests. Thus, to find a replacement for firewood, it was necessary to dig for coal, and this led to the invention of the steam locomotive, which was used to remove water in coal mines as well as to transport the coal to industrial sites.

So cooling may have brought on the Industrial Revolution, and the massive use of fossil fuels has brought on global warming. There is a profound connection between climate and history. The three great civilizations of Egypt, Mesopotamia,

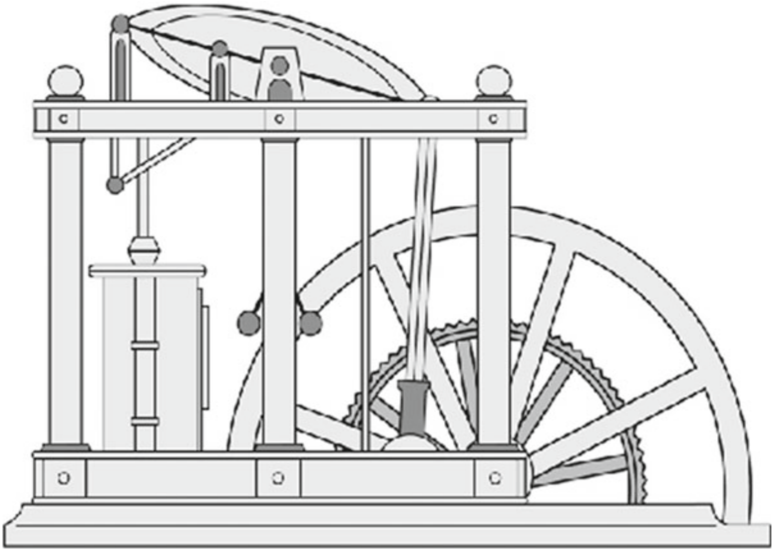

Fig. 6.1 A Wattsteam engine
Note: The steam engine fuelled primarily by coal propelled the Industrial Revolution in Britain and the around world. *Source*: Provided by Kagaku-dojin Publisher

and China were the products of climate change. All together, the global ecosystem and the human activities that depend on it make up one interactive system. Climate warming and cooling, and the changes attendant in the climate such as changes in precipitation, aridity, and humidity—these have had huge impacts on human activities. To adapt to climate conditions, humans changed their lifestyles and societal systems and developed technologies. The very history of humanity—the social disruptions, human migrations, wars, and so on—is a product of repeated cycles of climate processes over hundreds, thousands, and tens of thousands of years [4].

6.1.6 The Industrial Revolution and Modern Industrial Civilization

Modern industrial civilization emerged at the end of the eighteenth century, with the Industrial Revolution in England. The deciding factor here was James Watt's improvement of the steam engine in 1785. A prototype steam engine had already existed, but it was Watt who succeeded in converting the steam engine's energy from piston motion to rotational motion (Fig. 6.1). This was the birth of the reciprocating steam engine.

The steam engine brought about dramatic changes in human society. It was used to pump water out of coal mines, which helped to dramatically increase coal production. Railways were created, and the speed and carrying capacity of transportation jumped significantly. Coal provided the power for steam engines, and the railways made of iron made it possible to carry the mined coal great distances.

Fig. 6.2 The Ford model T
Note: In 1908, Ford Motor Company produced the first affordable automobile. Since then, automobiles have been a symbol of the prosperity of high-carbon society. Today, a hundred years later, automobile industries in the United States and around the world are facing a challenge. What comes next in the age of transition to a low carbon society. *Source of picture*: http://en.wikipedia.org/wiki/Ford_Model_T

The steam engine was also used in textile machines, which led to mass production of cotton yarn and the expansion of the cotton spinning industry.

Besides the steam engine, another important development early in the eighteenth century was a new iron-making process that used coke. Until then, wood charcoal was used in iron making, but that method required the large-scale logging of forests. At the time, England was suffering from a severe shortage of timber because forests had been cut down for fuel, which resulted in serious problems for iron production. Thanks to the steam engine and the use of coke in the steel-making process, iron could be mass produced, and this made it possible to manufacture machines and ships and other things from iron, and also made possible the construction of railroads.

Steam engines also had an enormous impact on the development of cities. Until then, factories were built along rivers to allow the use of water power, but the steam engine made it possible to construct factories in the suburbs away from rivers. The result was that emerging commercial and industrial cities such as Manchester and Glasgow experienced further growth.

The emergence of the key technology of the steam engine caused enormous changes in the economy, society, and even in politics. After the reciprocating steam engine came the steam turbine and other technological innovations such as the internal combustion engine that used petroleum-based fuel, but the basic framework of civilization born of the steam engine and coal has essentially remained unchanged. This is a civilization constructed on fossil fuels such as coal and oil—the “fossil fuel civilization.” In this sense, this is also a “high-carbon society,” and its manifestation is the automobile (Fig. 6.2).

Incidentally, China and Japan also had iron-making processes based on wood charcoal. Japanese writer and historian Ryotaro Shiba theorized that the reason China lost its forests was logging for production of iron over its long history. In ancient Japan, a group by the name of "Tatarashi" made iron in the mountains of the Chugoku district of the country. In the legend of the *Yamata no Orochi* (a mythical eight-headed serpent), red blood poured from the beast and the story tells that a sword was discovered in its body. One interpretation is that there was an iron-making group in the mountains, that it cut many trees, and that heavy rains caused a washout of reddish soil.

6.1.7 A New Civilization: Low-Carbon Societies

The emergence of global warming as an issue clearly shows us the limits of the fossil fuel civilization. Today humanity is beginning to search for ways to become a civilization based on technological systems that do not depend on fossil fuels. It is of historic significance that the term "low-carbon society" has come into common use recently. So now we must ask: exactly what is a low-carbon society? Simply stated, it is a society that uses the least possible amount of fossil fuels such as oil and coal. The ideal would be a society that does not use fossil fuels at all—a "decarbonized society" or a "carbon-free society."

If it was the appearance of the steam engine that brought about the modern industrial civilization—that is, the fossil fuel civilization—what technology holds the key to a low-carbon society? Can nuclear power replace fossil fuels as a source of energy? Or can renewable energy such as solar energy or biofuels do the job? Or will it perhaps be innovative technology such as nuclear fusion? Based on the progress in science and technology that we have witnessed in our own lifetime, and reflecting back upon the major socioeconomic changes we have experienced, we cannot help but feel that it is extremely difficult to predict the future. The capacity of the large computer we first began to use in about 1970 is no comparison to one of today's personal computers. It was beyond imagination that the Internet would spread as far and wide as it has. On the other hand, some technologies such as power generation from nuclear fusion have not made the progress people had expected or hoped would occur.

If nuclear power or some other future development of fusion power can replace fossil fuels, humanity may be released from energy constraints. But will the scenario be desirable for spaceship Earth? After being released from one constraint, it is likely we will crash into another. History is an endless repetition of this kind of endeavor, and there are no final answers.

6.2 Aiming for Sustainability

6.2.1 What Is Sustainability?

The principle of "sustainable development" was presented as a core concept at the Earth Summit in 1992, but what exactly is it? By way of background, it was the

World Commission on Environment and Development (WCED), established by the United Nations, that made the preparations for the Earth Summit. The commission's final report, issued in 1987 and titled "Our Common Future," was the first place this principle appeared [5, 6]. It defines sustainable development as development that "meets the needs of the present without sacrificing the ability of future generations to meet their own needs." At first glance this may not seem to be the easiest concept to grasp.

Recent debate about pension systems in Japan gives some good material to consider what sustainability really is. Pension systems are designed to maintain sustainability by having the younger working generation bear the burden of paying for the system, but as a result of the trend to lower birthrates and aging of society in Japan, there are now relatively fewer young people, and eventually the system could collapse. Increasing the size of the government's fiscal deficit as an economic strategy is another way to transfer economic burdens to the future. Indeed, deficit financing by government is public spending to meet the "needs of the present generation." An excessively heavy burden placed on future generations may render them unable to meet their own needs.

Economist Herman Daly proposed three precepts for the sustainable use of resources, the gist of which can be summarized as follows: (1) the rate of use of "renewable resources" (forests, fisheries resources, etc.) must not exceed the ability of the ecosystem to regenerate the resources; (2) the use of "nonrenewable resources" (fossil fuels, minerals, etc.) must be at a pace that does not exceed the rate of development of renewable substitutes; and (3) the emissions of pollutants must not exceed nature's self-cleaning capacity (or environmental space) [7]. The second principle here may be slightly difficult to grasp, but if we take the example of oil, anticipating the fact that oil will be depleted in the future, we should take a portion of the profits from the use of oil and invest it into the development of renewable natural energy to compensate for the depletion of the finite resources.

As for the sustainability of natural resources, there is a famous argument about the substitutability between "natural capital" (as in an old-growth forest) and "manmade capital" (as in a plantation forest). There is a stance that the natural capital has its intrinsic value that cannot be substituted by manmade capital, and we must strictly maintain the renewal capacity of the natural capital. There is another stance that if the function is the same, it is acceptable to substitute manmade capital for natural capital. The former is valued as "strong sustainability" and the latter as "weak sustainability."

6.2.2 Waves and Cycles in the Environment and Economy

We seem to believe that it is entirely normal to expect an economy to always continue growing, but can we really expect that to happen? During this century the world population is generally expected to continue increasing, but if the world population started to actually decrease, what would be the implications for the economy?

It is well known that the economy moves in waves, but it is important to also realize that economic waves greatly affect the general level of interest in environmental problems, the willingness to tackle them, and the size of investments in the environment. A growing economy means rising consumption of energy and resources, and also a steadily growing burden on the environment, but a growing economy also boosts investment in research and development, and facilitates progress in efforts to seek harmony between the environment and human activities. Conversely, during a recession, the consumption of both resources and energy drops, and overall investment into research and development also tends to drop.

In our experience of the past 50 years or so, there have been several waves in the environment and economy. During the period of rapid economic growth from the 1960s through to the oil shock of 1973, Japan experienced many problems with industrial pollution, but it also turned into a period of large investment into pollution prevention. The 1980s were rather like a winter for domestic environmental policy in this country. Nevertheless, at the international level, the issue of global warming was taken up seriously, and along with the end of the Cold War between the East and West, and the expansion of the European Union eastward, the international community made some progress in environmental policies, with Europe leading the way. During the 1990s, even though Japan suffered from the after-effects of its burst economic bubble, it still made considerable progress in environmental policies, spurred on by an international tailwind.

6.2.3 The Drivers of Progress

Various global economy and technology scenarios have been developed to help predict future global warming, but not one of them includes a scenario for an extended period of negative growth for the global economy [8]. This seems somewhat strange. The basis for economic forecasting is our experience of, at the most, the past 100 years or so. There have been anomalies in history, such as Great Depression that started in 1929 and the Second World War from 1939 to 1945, but the general assumption has been that human society will continually move in the direction of progress, expansion, and development. Actually, however these things are not guaranteed.

The real driver of human progress is the power of science and technology, and the source of this power is none other than human creativity. New inventions, discoveries, and technological developments have created new products, promoted human health, and extended human life through advances in medicine [9]. For sustainable development from now on, the key issue is whether we can develop and spread technologies that will contribute to both environmental improvements and economic growth. In 2008, Barack Obama, as newly elected President of the United States, announced initiatives that would create much employment through investment in areas such as improving buildings to boost energy efficiency; expansion of public transport and rail freight; development of advanced power grid systems; wind power, solar power; advanced biofuels, and so on.

The macroeconomic model of economic growth tells us that by diverting a portion of current production to invest for the future it is possible to increase future production capacity, and we are told that this facilitates sustainable economic growth. If the economy falls into a recession, however, the private sector has fewer funds to invest, so the role of governments becomes more important.

Aiming for economic revitalization during the 1980s when the economy was in recession, the United Kingdom's Prime Minister Margaret Thatcher and United States' President Ronald Reagan were among the leaders promoting neoliberalism with its focus on the role of private sector activity. As this book is being written in early 2009, those two countries are both embracing policies that enlarge the role of government. This step is made necessary by circumstances, although many people are concerned about growing fiscal deficits. With combined national and local government fiscal deficits of more than 800 trillion yen, or 1.6 times gross domestic product, Japan too is in a serious situation today. In this context, we are being tested as to whether or not we can read the trends and make the right economic and environmental decisions.

6.2.4 Societies with Sound Material Cycle

On the surface, the "metabolic" mechanisms of input and transformation of resources and energy associated with human activities seem to resemble what happens in natural ecosystems. Humans live by eating food every day, digesting it, and excreting the waste, and the natural world contains ecosystems that completely recycle this waste. Sustainable systems incorporate mechanisms to maintain this kind of steady state. The natural world has perfect recycling systems based on metabolic mechanisms. In contrast, our modern industrial civilization is built upon the mass consumption of buried resources such as fossil fuels and minerals. The products produced are difficult to dispose, and some of them become hazardous waste that accumulates in the environment. This scene is very different from recycling in the natural world.

The field of "industrial ecology" has appeared as a discipline that analyzes the material flows generated artificially from human activities in modern industrial societies. Since about 1980, experts have been attempting to redesign the material circulation systems of our modern industrial civilization based on lessons from the natural world. Related concepts included reducing resource inputs and environmental pollutant generation to the smallest possible levels per unit of production, and these measures led to the concepts of "eco-efficiency," "factor four" (doubling wealth, halving resource use), and "zero emissions" [9–12]. The concept of "sound material-cycle society" (or a "recycling-based society," in Japanese *junkangata shakai*) was born in response to the serious issue of trying to stop the constantly growing volume of waste in society. Japan even passed the "Basic Law for Establishing a Sound Material-Cycle Society" into law in 2000.

We must not forget, however, that large differences still exist between the material cycle of the natural or biological world and the materials cycle in modern industrial society. The former is powered by solar energy and is based upon plant photosynthesis and circulation in the food chain, the latter upon fossil fuels and nuclear power. Many industrial products contain a variety of regular and rare metals as well as persistent chemicals, which when left in the environment can become substances hazardous to ecosystems. In contrast, "manufacturing" in the natural world was self-organizing through the long processes of evolution, so anything created that has finished its purpose is decomposed again naturally, and nothing toxic remains.

During this century, manufacturing technology will change dramatically. One day, we will probably be able to recycle and reuse most of the existing above-ground stock of metals, and we will probably be able to create high-performance materials using biotechnology. It may be also possible that computers will use biochips or neural circuits instead of today's solid state integrated circuit chips. The key to success may be the improved understanding of and learning from the miraculous functions of living things and ecosystems, and the development of technologies that mimic them.

6.2.5 Social and Economic Paradigm Shifts: Dematerialization, Less Ownership, More "Servicizing"

The concept of "sound material cycle" originated in Germany in the 1990s from the concept of "Extended Producer Responsibility" [13]. People thought it was unacceptable for municipal governments to bear all the responsibility of collecting and disposing of household waste. The manufacturers and retail stores that made or sold the products that ended up as waste should bear some responsibility. This concept was quickly embraced in Japan, which quickly enacted the legislation for a sound material-cycle society.

A fundamental shift in thinking is still needed to incorporate the concept of extended producer responsibility into the economic system that we will simply take for granted.

Today when we purchase a product, we take ownership of that item, and when we are finished with it, the used product becomes waste. But if the manufacturer were to take the item back again, the ownership would revert back to the manufacturer. In such a scenario, it would be more sensible to *lease* the item instead of *purchasing* it. In that case, the ownership would stay with the manufacturer throughout, and the user would enter into a leasing contract with the manufacturer. This is already exactly how we expect things to happen with a rental apartment or an office.

Let us consider how this would work with an automobile. What is the reason that we purchase a car? Do we own cars as status symbols? Or are they for the purpose of transport? Even if you own a luxury import car, what is the point in owning it if you have little opportunity to drive and it stays parked most of the time? If the car is only driven occasionally, it would be much cheaper to rent a nice car only when needed.

Property and consumer durables (e.g., houses, automobiles, household appliances) have both ownership value and "usership" (or service) value. Societies in the future may place more importance on the value of use, or the value of service that the item can provide rather than on ownership. Ultimately the outcome is decided by consumer preferences, but people could choose to lease or rent the car of their choice just when they need to use it. This attitude could be a way for society to achieve a major transformation toward "servicizing," shifting away from ownership and instead placing value on the services they can obtain from things.

6.2.6 Transition Toward a Low-Carbon Society

Technological progress since the Industrial Revolution has been remarkable, but it is fossil fuels that were the driving force behind economic growth. Fossil fuels made possible the production of great amounts of iron, and as a raw material iron made it possible to build tall buildings, ships, automobiles, and other many items. Almost all forms of transport—automobiles, ships, aircraft, and others—depend on fossil fuels and internal combustion engines for motive power.

A low-carbon society is one that has shifted away from its dependence on fossil fuels. Expanded use of nuclear power might be one way to follow this path, but it comes with safety concerns, and there are also risks such as the proliferation of nuclear weapons and terrorism in politically unstable countries or regions. Within Japan, the natural energy that can be used anywhere is solar energy. It may be difficult to have solar replace all uses of fuels, but in small and medium cities with good climatic conditions, it is possible to use solar to meet almost all noncommercial energy demand, such as for heating and cooling.

The automobile was a phenomenon of the fossil fuel civilization, which is a high-carbon society. Diverting biofuels to automobile use sets up competition for agricultural resources between production for food and production for fuel, so there are quantitative constraints on the use of biofuels as a solution. Today, Brazil and the United States show great potential for biofuel production, and there are concerns that biofuels could be the next strategic commodity after oil. Ultimately, however, we must redesign our cities and transport systems to allow us to live without depending on the automobile.

During the first half of this century, economic growth will continue in countries with large populations such as China, India, and Brazil. Some are strongly concerned about the pressures of resource demand in these countries. The above-the-ground stock of iron in industrialized countries exceeds 10 tons per capita, but in China it is still only about 2 tons per capita. Even if that country's annual production of 685 million tons in 2011 was an anomaly, iron is still needed in China, so production is likely to continue until aboveground stocks reach at least two or three times the current level.

The foregoing may seem relatively pessimistic, but there is also hope. Japan is already experiencing low birthrates and the aging of society. There is a big chance that population growth rates in developing countries will be below current projections.

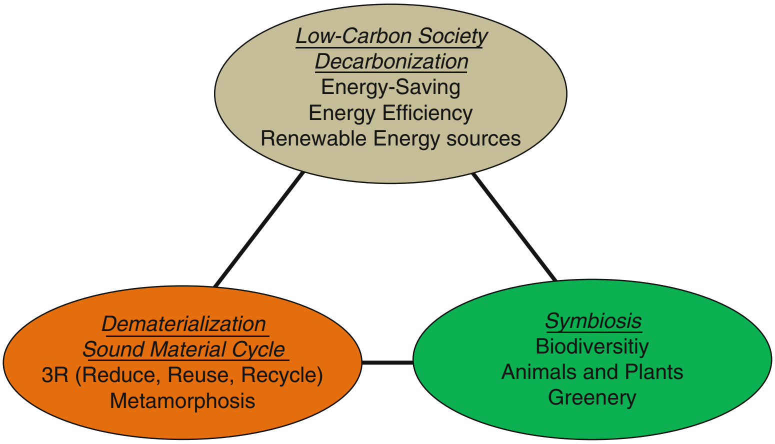

Fig. 6.3 Triple goals of sustainability in the twenty-first century

If world population growth rate slows after the middle of this century, the pressure on the environment will quickly decline. What Japan is experiencing now is already proof of that. Basic commodities such as iron are already being recycled extensively, so the amount of new production from raw materials (or virgin resources) can be expected to drop dramatically in the future.

Biotechnology holds much promise as a core technology for a low-carbon society, but for that to happen, it is essential that biodiversity be preserved. Biotechnology is likely to be a critical technology, whether it be for food, biofuels, chemicals, pharmaceuticals, or environmental remediation. In the end, we must aim simultaneously for three goals: a low-carbon society, coexistence with nature, and sound material cycle (Fig. 6.3).

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Chapter 7
The Environment as a Commons: How Should It Be Managed?

7.1 Who Owns the Environment?

7.1.1 The Tragedy of the Commons

"The Tragedy of the Commons" is a metaphor rich with implications for the essence of environmental issues, and those words formed the title of an article by biologist Garrett Hardin, published in 1968 in the journal *Science* [1]. Hardin's basic scenario is based on a common pasture (the "commons") where many herders may graze their cattle. All is fine when the total number of cattle is low, because even as the herders increase their herds, there is still adequate capacity in the pasture. As the number of cattle increases further, however, the capacity for grazing drops, and the pasture gradually becomes crowded. Eventually, further increases in the number of cattle push the pasture pass a critical point at which it is irreversibly damaged.

The main points of this metaphor are that individuals—each seeming to act rationally—will act in a way that crosses a critical point with an undesirable result for society overall, and that behavior based on short-sighted desires of individuals will result in the over usage of shared resources. Looking around, we can see many examples of these dynamics. If just one factory dumps a relatively small amount of effluent into the environment, there may be no serious problems. If many factories operate similarly, however, the pollution will exceed the environmental capacity of the river, and not only might the local residents suffer from illness, the factories might find themselves unable to continue operations. Traffic jams and damage to public parks also share similarities with these dynamics.

In Hardin's metaphor, all herders have as much access to the pasture as they like. It might be possible to avoid irreversible damage to the pasture, however, if the pasture has an owner and some usage restrictions are imposed, or if an owner charges a usage fee, or if a wise person proposes limits on the number of cattle that can be allowed to graze there and everyone respects that limit.

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7.1.2 Why Does the Tragedy of the Commons Exist?

Three factors end up causing excessive use in the tragedy of the commons: (1) a system of free access, (2) externality, and (3) short-sighted self-interest. A system of free access—with resources that are shared and available for anyone to use—can lead to excessive use as a result of the ambiguity of ownership or usage rights; the management structure is not clear, so each individual can act as he or she wishes. We discuss externality further in Chap. 8, but for the moment we define this as the impact of individual behavior on the life of other individuals that takes place in the absence of economic transaction. Short-sighted self-interest is a characteristic by which individuals choose to act in pursuit of their own short-term profits.

The first two factors relate to the common features of what may be classified as public goods, such as roads and parks; for these, ways are needed to prevent excessive use and congestion. To begin with, owners or managers must clarify the system of management. To this end, the parties who depend on the commons need to decide on shared rules for management, and this is where a variety of laws and international treaties relating to environmental protection come in. For matters that have not yet been formally put in writing, often this function is fulfilled by customs and conventions that have been observed by the local community. Another approach is through economic means, by internalizing the costs and benefits of environmental management into economic behavior. The introduction of emissions trading systems and environmental taxes for greenhouse gases is also in line with this type of approach; these are solutions that follow the principles of the market economy.

A complete management system as mentioned above may automatically prevent behavior based on short-sighted self-interest, but another approach to change individual behavior is through proactive environmental education and provision of improved information.

7.1.3 The Prisoner's Dilemma

The "prisoner's dilemma" is another metaphor that attempts to explain why individuals in a commons may behave in a short-sighted and uncoordinated fashion [2, 3].

In the United States, it is common for prosecutors to negotiate with criminals to obtain evidence to settle a case. In one version of this metaphor, prisoners A and B, who committed a crime together, have been apprehended and are in solitary cells where they cannot communicate with each other. Because both of them have committed other minor crimes, neither can avoid a 1-year prison sentence, but if evidence is found for the crime in question they could get 10 years in prison. The prosecutor tells A that if he remains silent but B exposes who committed the crime, the prosecutor will seek 10 years imprisonment for A, but if A confesses first, then his sentence may be reduced to 3 years. The prosecutor engages in the same negotiation with B. In this case, if both prisoners remain silent, both will be imprisoned for only 1 year. The worst case for them would be that both prisoners confess, in which case both would spend 8 years in prison (slightly reduced for having confessed). If one prisoner remains silent but the other confesses, the silent one will spend 10 years in prison, and the one who confessed only 3 years.

Let us imagine for a moment what goes on in the mind of each prisoner. If they can trust each other, both will remain silent, but if they cannot trust each other, they will both confess. This metaphor closely resembles the psychological aspects of the individuals in the use of a commons: each individual believes that even if he or she behaves with restraint, others will not exercise restraint. The result will be excessive use of the commons.

To avoid the prisoner's dilemma, parties must communicate with each other and cooperate based on mutual trust. These conclusions are important when dealing with environmental problems.

7.1.4 The Global Commons

The term "commons" simply means "common land" or "common property," but the term for "common" can imply two situations: (1) the common owners are clearly known, and (2) the common owners are not clearly known or they are numerous and unidentifiable.

In the days before today's market economy became so pervasive, local communities in many places in the world jointly managed common farmland, pastureland, forestland, wells, and other natural resources, in ways that allowed them to continue using the resource sustainably without exceeding the regenerative capacity of the environment. In some cases there were clearly articulated rules in the local communities, and in other cases implicit rules that set forth the rights and responsibilities of commons users. This was possible when the number of people involved in the commons was small enough that people could identify each other directly.

Problems begin to arise if the users are unidentifiable and numerous, or if the large number makes it difficult to form consensus on the rules of management, or if the rules are difficult to enforce because of the presence of "free riders" who believe they are likely to face no penalty if they alone violate the rules. This is exactly the problem we can see today in the use of "environmental resources" such as the global atmosphere and oceans as dumping grounds for waste, under our globalized economic and industrial systems. Humanity has recently begun to see our planet's atmosphere and oceans as "global commons" and to establish ways to manage them. Examples can be seen in the international treaties concerning climate change, the ozone layer, and other global commons.

International treaties and agreements—the rules for all of humanity to participate in management of the global commons—are essential, but a difficult problem arises regarding how to negotiate with the conflicting interests of developed and developing countries. The Rio Declaration and Framework Convention on Climate Change address this problem with the phrase "common but differentiated responsibility" [4]. It was ultimately possible to reach consensus with developing countries by recognizing that even though developed countries—with a long history of modernization and industrialization—have greater responsibility, all members of the international community share some responsibility.

7.1.5 Anthropocentrism and Ecocentrism

People may come across slogans like "Let's protect the global environment together," and "The Earth belongs to everyone." Behind these slogans is the abstract idea that the environment is the shared property of all people in a community—or all citizens in a country, or even for all of humanity on the planet—and some ambiguity about which entity should protect the environment. This brings us to a big question: Who owns the environment and who should take responsibility to protect it?

Ultimately, the global environment is necessary for all living species, not just for the one species known as *Homo sapiens*. One stance on environmental protection is "anthropocentrism," which asserts that humans have a privileged position among all species. Another stance is "ecocentrism," which puts the rights of all species on equal terms with those of humans. Environmental philosophers and ethicists aside, people most probably vacillate between the two positions.

The first principle in the "Rio Declaration on Environment and Development" adopted at the Rio Summit in 1992, was this: "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature" [5, 6]. These words, while candidly recognizing that it is humans who are causing environmental problems and who hold the keys to solutions, do not state that humans must cease their activities. While stating the constraint of being in "harmony with nature," it also says that humans are "entitled" to a healthy and productive life. This text was the result of negotiations to reflect developing countries' assertions that they too had the right to seek prosperity, but it is obviously an articulation of an anthropocentric stance on the environment and development.

In contrast to anthropocentrism, ecocentrism recognizes that the global ecosystem is based on coexistence, with all species engaged in interactions with others; human beings are only one constituent in this system. Similar terms include "non-anthropocentrism" and "biocentrism."

7.1.6 Deep Ecology

"Deep ecology" is one brand of ecocentrism that was first proposed in 1973 by Norwegian philosopher Arne Næss [6]. At the time, a strong consumers' movement was influential in the public debate in Europe and the United States, as evidenced by the popularity of consumer advocate Ralph Nader, and the environmental protection movement was also strong. In that context, Næss asserted that "shallow environmentalism" sought solutions to environmental problems by reforming economic and political systems, while "deep ecology" sought internal reforms of the human consciousness about nature. He explained that by reforming our internal attitudes by realizing that all things in the biosphere are equal, we can be liberated from mass consumption, the subjugation of nature, and the chasing of fads that modern civilization has wrought.

The foundations of anthropocentrism were formed by Christian teachings that God created Man; that much is certain. Western countries where Christianity is strong also happen to be where ecocentrism was born. One might conclude that Eastern thought—such as the teachings of Buddhism about reincarnation and its warnings against the destruction of life—is close to ecocentrism, and apparently Næss was influenced by Eastern thought, but there is little evidence that Asians actively influenced this debate.

There may be many ways to think about environmental protection—whether the approach be anthropocentrism, ecocentrism, or something else—and people may have different views that vary depending on the individual, country, or even religion, but thinking and stances on this topic can be summarized generally in a few categories. If we put the "cowboy economy" thinking that says it is completely acceptable for humans to use all the resources they want on the far right, and "deep ecology" on the far left, then in the middle are other representative stances, such as "neo-classical environmental economics," "resource economics," and "ecological economics." These we discuss in more detail in Chap. 8 under the topic of "environmental economics." Figure 7.1 illustrates the relationship between various environmental thoughts and disciplines.

7.1.7 Who Owns the Environment?

Long ago, no one claimed ownership of the land, forest, water, or air—the many resources of the Earth. In economic terms these were "free goods." Over time, it came about that the persons who cleared the land became considered as its owners, but private land ownership did not just begin suddenly. In some countries, land that first belonged to the state was allocated to individuals, and that was the start of the private ownership of land. Eventually, a small number of landowners held vast tracts of land, and a large number of farmers owned no land—and this bipolarization became a major problem in many societies. It was in the twentieth century that Russia and China had revolutions attempting to resolve this problem.

Today, almost all land in the world is the territory of a state, but one exception is Antarctica. The Antarctic Treaty, concluded in 1959, froze countries' territorial claims on this continent. In the global climate system, the roles of the Antarctic and the Arctic are exceedingly important. If human activity in the Antarctic increases for reason of resource development, the ice will melt further, and there are concerns about this causing serious impacts on the global climate system.

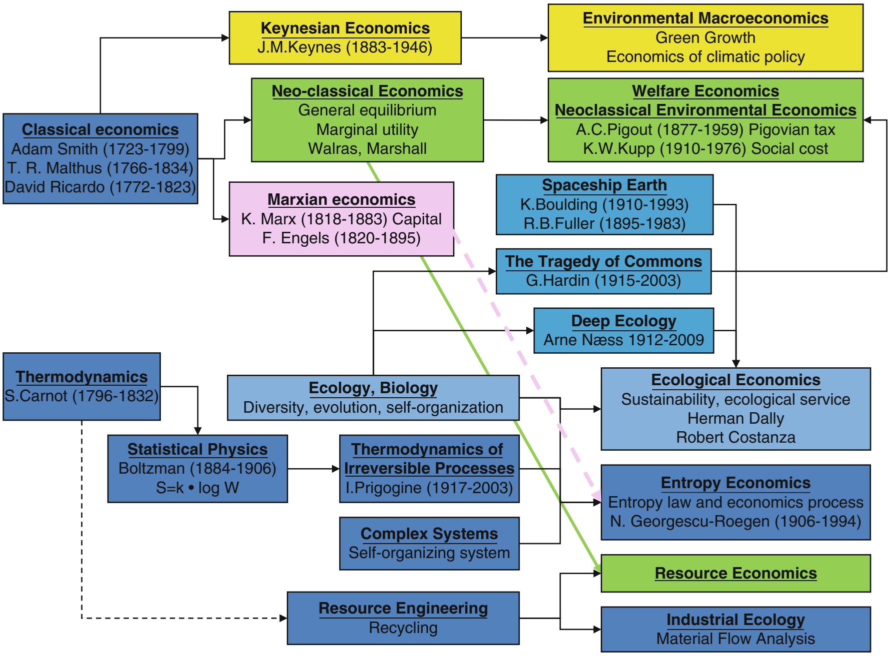

Fig. 7.1 Relationship between various environmental thoughts and academic disciplines

Most of the Earth's water resource resides in the oceans. International law incorporates the concept of "high seas" (or "international waters"), but who "owns" the vast amount of water in the Pacific Ocean? There are no regulatory provisions to answer this question. Rain falls to the Earth from the sky and flows through rivers. In this case, there are many examples of national laws on water usage rights, water drawing rights, or some similar form of rights. In the past, many conflicts were fought before rights were established for access to water resources, but once rights were established, many of the problems were resolved.

7.1.8 Air and Water Are Not Free: Managing the Dumping Grounds

Long ago, water and air were free, but today the situation is very different. We now purchase drinking water in plastic bottles, and even the air has ceased to be a completely free good. Air and water are vital resources for the survival of living things, but there are two dimensions to be considered. First, living things need these resources for respiration and to sustain the body. Second, living things need them as a place to dispose of waste material and waste heat. These two dimensions are inextricably linked: if a large amount of waste is disposed here, the air and water will both become polluted, their quality as resources will deteriorate, and the existence of living things will be at risk.

Environmental issues newly emerged as the problem of management of air and water (rivers, lakes, oceans) in the context of the disposal of waste generated in the course of human activities. Because the amount of disposed pollutants, greenhouse gases and other wastes increased suddenly, restrictions were imposed on the disposal of waste, and fees were put into place for the use of air and water as a dumping ground for waste. Alternatively, it became necessary to purchase rights or obtain permits to "dump." Examples of such tools are surcharges on industrial effluent, or emissions trading for greenhouse gases such as carbon dioxide. Land is similar. No one now can dispose of waste just anywhere, and when it is hauled to a designated landfill in the Tokyo metropolitan area, for example, the disposal fee is 10,000–20,000 yen per ton.

The air we breathe is still a free good, but limits are now being imposed on how much we can use the atmosphere to dispose of air pollutants (carbon dioxide, sulfur dioxide, etc.). Polluters should either pay to dump into the atmosphere (e.g., a carbon tax, or a fee of a few thousand yen per ton of carbon dioxide or other emissions from fossil fuel sources), or purchase usage rights (emission rights). In this sense, the time has come to turn the atmosphere—until now a free good—into something with a price on it and for which we must pay for the right to use.

Above we discussed sustainable joint management by local people sometimes works well for a local commons, but for a global commons such as the atmosphere, it is not so easy to reach consensus on joint management. Under such a situation, a price is set on something that was until now a free good, or some other economic method is used to establish user rights and then trade them on the market. Already the world is starting to implement such methods.

7.2 Managing Local Commons Sustainably

7.2.1 The Tragedy of the Commons Revisited

In Hardin's version of the tragedy of the commons, the commons ends up damaged, but does that metaphor always fit? Are humans always pursuing their individual interests and so indifferent to the common good? It is worth noting that there are various possible types of commons. The "local commons," or common property jointly managed by local people, is one example with a real history of self-regulation and sustainable management by local entities.

Japan has a long history with an approach like a common land (*iriaichi*) for village forests (*satoyama*) and woodlands (*sanrin*), where villagers thinned the trees to obtain firewood and charcoal and also procured forest material and fallen leaves for use as compost. Each village had its own regulations for use and management of the commons, and villagers respected them. These rules played a big role in protecting the *satoyama*, a landscape of which is shown in Fig. 7.2. These customs were in

Fig. 7.2 Landscape of Satoyama (village forests) in Japan. *Source*: pictures are provided by Yuko Sase

place before the establishment of modern law during the Meiji period (from late 1800s to early 1900s), during which many of the village- or clan-held lands became state property. Under civil law, access rights became recognized as real rights and villagers were able to possess those rights to log and use these lands.

In medieval England, there was widespread use of the three-field system (using rotation of cultivated, pasture, and fallow land) of farming in rectangular fields within the lands granted by a feudal lord, and there was also a year-to-year rotation of the land farmers were allowed to use. Access rights were granted for the forests, pastures, and meadows near the villages to allow grazing, wood collection, and peat collection. Grazing rights were valuable, and detailed rules intended to prevent overgrazing dictated the type and number of livestock that could be allowed to graze. This system ensured that organic material to provide soil nutrients was circulated within the region, and that land productivity was maintained in a sustainable way.

7.2.2 Another Tragedy of the Commons: Neglect and Abandonment

The original concept of "tragedy of the commons" referred to the excessive use of natural resources, but a tragedy can equally occur from lack of use. Before our modern commercial economies, voluntary rules and contractual relationships among community members were often used as social systems to manage the commons and ensure a sustainable local supply of resources. These systems made it possible to continue enjoying the gifts of nature for free without overexploitation, but with the commercialization of the economy many of these systems are collapsing.

In sixteenth-century England, the enclosure movement increased the number of farmers without access to land as common land was taken into private ownership. The growth of the spinning industry had boosted demand for wool, with the result that land that previously alternated between use for cultivation and grazing was converted into larger pasturelands. The same kind of movement occurred in the eighteenth century during the Industrial Revolution.

In post-War Japan's process of industrialization and urbanization, the system of the local commons ceased to function properly as farming and mountain village populations declined and local communities weakened, and at the same time, demand for firewood and charcoal decreased, making it unnecessary to thin the forests and obtain wood. In Thailand and other countries, commercial logging expanded under government guidance, but this led to forest loss and also weakened local communities.

Japanese farming villages also have a long history of jointly managing farmland and pastureland. Many cases remain today as joint-use of forests and joint ownership of forests. The *satoyama* and *sanrin* were sustainable and excellent systems of using nature, managing nature, and protecting nature on shared land. The fact that these systems are in decline means that Japan risks losing these long-cherished rural landscapes that were places of interaction and harmony between people and nature. The threats today, however, are not from the overuse of commons, but rather from their neglect and even abandonment. The reason for abandonment is, simply stated, a drop in productive value. These are the outcomes of structural changes from industrialization and the failure of government agricultural policies.

7.2.3 Ways to Manage the Local Commons

If *satoyama* and other forms of local commons can survive without being abandoned, there are ways to manage them without letting them be overexploited. On the other hand, with air pollution, river pollution, and global warming, we are less concerned about their abandonment, but more concerned about overexploitation of environment resources as dumping grounds of pollutants and wastes. For issues such as global warming, all of humanity must be involved in the management of the global commons. In contrast, for a local commons, it is possible for the local community or a citizen group to guide its management.

Many farm lands and pasture lands were lost in England as the Industrial Revolution progressed, and people became concerned about the loss of the amenity functions of nature. Citizens of London, Manchester, and other cities became active in movements to protect open spaces as places of amenity and recreation, and one result was the creation of public parks as spaces for public access. It was in this context that the National Trust for Places of Historic Interest or Natural Beauty was established in England in 1895.

If the regional scope is well defined, the atmosphere and rivers can also be managed as a local commons by local communities. Examples include the water management policies of Gujo Hachiman, an historic town in Japan's Gifu Prefecture, or the ban on vehicles powered by internal-combustion engines in the Swiss town of Zermatt. Key features where local commons are successfully maintained stably and for the long term often include the following: (1) individuals clearly recognize the existence of the commons and the community accepts it as legitimate; (2) management and monitoring systems have been properly established and the scale is small enough to prevent free riders from exploiting the system; (3) the resources in question are essential for the survival or livelihoods of the local people; and (4) rights and obligations relating to the use and management of the commons are fair.

7.3 Managing the "Negative Commons"

7.3.1 The Negative Commons: Unpopular Facilities

We have discussed local commons and global commons, and saw that a local commons can be sustainably managed if the local community decides on rules for its management. But the commons typically discussed so far has valuable uses as a resource, such as common land and public parks. We could label these as "positive local commons," which suggests the existence of something we could call a "negative local commons." Examples might include a garbage incineration plant, a municipal waste landfill, or a reprocessing plant or storage site for nuclear waste. As a recent example, we could also mention treatment facilities for toxic chemicals such as PCBs.

These facilities all are involved with the treatment of waste and are owned or managed by the state, the local government, or a special corporation, so they do not strictly meet the conditions for being "public goods" that would involve common ownership, common use, or nonexcludable use by individuals. This is simply because, for example, in Japan today the latest technologies are being used and the government or public sector is entirely in charge of their administration.

A common urban sight in developing countries is the scene of garbage simply piling up in empty lots, where people dispose of trash as they wish. Japanese cities were in a similar condition until the 1960s, and what was labeled the Tokyo Garbage War occurred in the 1960s when Koto Ward residents fought to prevent trucks from carrying garbage through their neighborhoods to a garbage landfill site on reclaimed land in Tokyo Bay. If left to their own devices, people may tend to simply throw their garbage out anywhere, so disposal sites are established to prevent that, but then problems arise with site selection and operation of the facilities. Why? It is because the site becomes a "negative local commons." Facilities such as nuclear power plants, airports, and garbage incineration plants are needed for the public benefit, and people may understand their value, but many do not want such a facility built where they live: this is where the term NIMBY or NIMBYISM originated, which stands for "Not In My Back Yard."

There are various reasons that someone might not want a facility built in their own neighborhood, but one typical reason is the fear that it will be the locals who become victims in the event of some kind of accident. The degree and nature of fear about facilities differ depending on the facility. For example, with one the chance of an accident may be small, but if one does happen the damage may be serious. With others, accidents may occur more frequently, but their scale of damage may be minor.

7.3.2 Risk Familiarity Reduces Fear

Even though the risk of being exposed to radiation from a nuclear power plant accident is less than the risk of X-ray exposure in a medical checkup, experts have found that the public in Japan is more afraid of the former; public concerns about nuclear accidents mounted after the nuclear crisis in Fukushima in 2011. The probability of a giant meteor striking the Earth is once in about one million to tens of millions of years, so the likelihood of this happening in one's lifetime is virtually nil. The likelihood of getting struck and hurt by a bicycle on the road is much greater. Even so, some people are more afraid of being struck by a meteor.

American psychologist Paul Slovic has studied public perceptions about the risks of extreme events and the big differences between experts and the average person in the understanding of risk [7]. The word "risk" is itself difficult to define, but here we will refer to it as both the probability of an accident or extreme events occurring and the extent of damage in the case of accident. In research targeting American perceptions, Slovic identified two factors in risk awareness: "dread" risk, which is a feeling based on the expected extent of damage in the event of an accident, and "unknown" risk, which is the lack of knowledge about the situation or phenomenon.

Slovic studied 81 subjects and created a conceptual map of the degree of fear people felt about the subject and how much (or how little) they knew about the subject. Figure 7.3 is a plot of these subjects. Comparing a nuclear power plant accident with nuclear war, American citizens are more afraid of nuclear war, and believe that they know more about it. Conversely, they do not believe they know much about nuclear power. Regarding automobile accidents, even though the chance of personally being hurt in an accident is relatively high, individuals think they know much about it and are not very afraid. Regarding the risks of drinking alcohol and smoking, they feel they know them well and are not very afraid. What we can understand from this research is that we have less fear for things that we experience on a daily basis. As we get accustomed to something we stop being afraid of it, and if we are hearing about it regularly in the media, we begin to think that we know a lot about it. For things that people typically do not experience on a day-to-day basis, there is a tendency to feel excessive fear, because they do not have a direct sense of the probability of an accident occurring or the extent of damage if an accident does occur.

7.3.3 Waste Incineration Plants: The Dioxin Problem

Waste incineration plants are typical "NIMBY" facilities, but in Tokyo, their emissions stacks punctuate the urban skyline. Because Japan has policies that require waste be handled with inside the municipality that produces it, the waste cannot be transported elsewhere. In a large metropolis like Tokyo, the only option is to build an incineration plant in each ward of the city, even if that means locating the plant right beside a business district or residential area.

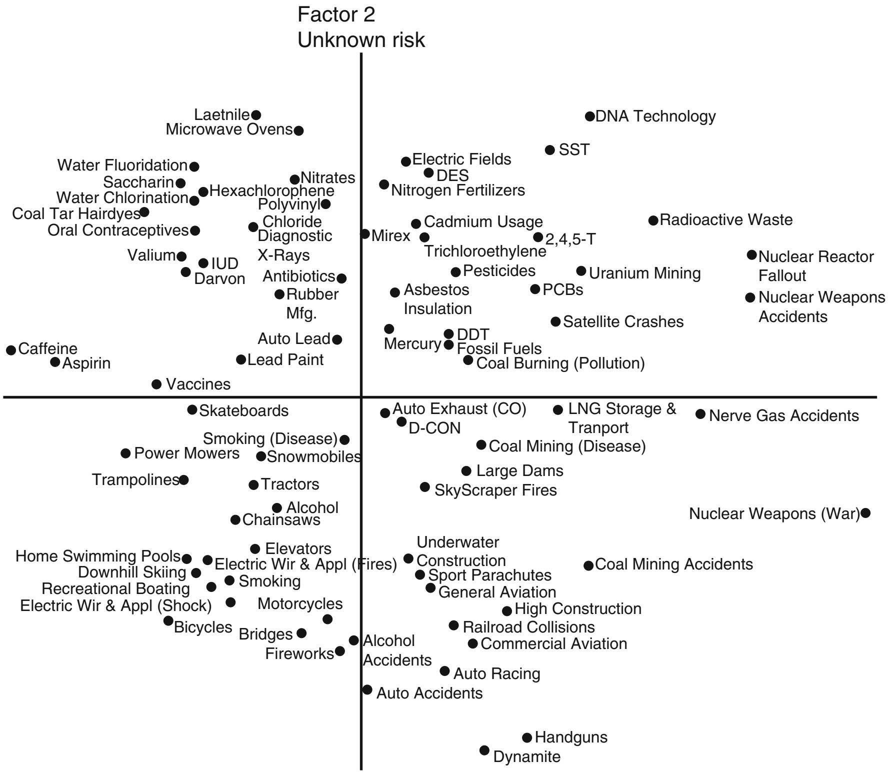

Fig. 7.3 A plot of 81 hazards in terms of "unknown risk" (factor 1) and "dread risk" (factor 2) *Source*: Paul Slovic and Elke U. Weber: "Perception of Risk Posed by Extreme Event." (from "Risk Management Strategies in an Uncertain World" Conference, Palisades, New York, April 12-13, 2002)

In the 1990s, the issue of dioxins emitted from incineration plants all over Japan became a major public concern, but by replacing the old facilities with those using the latest technology, it became possible to reduce dioxin emissions quite rapidly to only a few percent of the original levels. In Tokyo today, incineration plant stacks are present among the tall buildings, and it seems that waste incineration facilities are an accepted part of life in large cities.

Plans are being developed to build incineration plants in cities such as Beijing and Seoul, but residents there have expressed strong concern and opposition. According to comparative research, citizens in Seoul have a stronger sense of dread about waste incineration facilities than in Nagoya Japan. This is probably the result of fewer cases of incineration plants and a shorter history of having been built in Seoul so far compared to cities in Japan. Even though incineration plants are still generally disliked by Japanese citizens today, they have had longer experience of them being built in their cities and with touring such facilities, so the level of apprehension has diminished (Fig. 7.4).

Fig. 7.4 Waste incineration plant in Tokyo

7.3.4 Different Approaches for Different Types of Commons

Generally, commons could be described as local or global. Global commons require international rules such as treaties for their management. Even though some people still think that biodiversity issues are more related to the local community level, there is growing awareness that biodiversity should be managed as a global issue, and international treaties have been created to address this issue. For local commons that are valued for their potential to be used as "resources"—such as public parks and village forests—it is possible to avoid *excessive use* by creating resources management rules, if the number of parties involved is not too large. But Japan today is experiencing the deterioration of some commons such as village forests because of the lack of use and the lack of people to manage the commons.

The environment is often used as a dumping ground for waste (examples include air and water pollution, greenhouse gases, municipal waste, and nuclear waste). Various ways can be used to control this use including regulations to control the disposal of waste, systems for charging fees (environmental taxes, etc.), and systems that make it mandatory to obtain a right (or permit) for disposal.

Nuclear power and waste incineration plants are necessary for the public benefit, but because citizens are strongly concerned about accidents, such facilities could be viewed as "negative commons." People have a tendency to have excessive concern about the risks that they do not experience on a day-to-day basis. Expert data on the probability of an accident occurring and the extent of damage in the case of an accident occurs are often not effective in alleviating concerns. The Japanese experience with waste incineration plants shows that familiarity with risk reduces fear.

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Chapter 8
Economics of the Environment

8.1 The Dawn of Environmental Economics

8.1.1 The Global Environment and Economics

Neoclassical economics is a body of economic theory that took shape at the beginning of the twentieth century. It largely ignored the environment for many years. Goods and services traded on the market are given or attached a value. Air, water, and ecosystems, however, were used as free goods—or virtually for free—so no market existed for them [1–3]. They were overconsumed because they had no charge attached and could be used any way anyone wished. The result was pollution and environmental deterioration.

From a fairly early stage, Arthur Cecil Pigou and other economists did, in fact, discuss external effects of economic activities—benefits and losses that do not pass through the markets—but industrial pollution and other types of pollution did not immediately become major topics of research in economics [4]. It was during the 1960s, with the problems of industrial pollution already erupting, that economists became aware of the shortcomings of mainstream economic theory. Finally, global-scale problems such as global warming and the loss of tropical forests triggered an awakening, and at last the connections between the global environment and the economy came into the spotlight.

The global climate system and ecosystems had not been seriously addressed in economics until this point, but a new economics emerged in the 1980s, called "ecological economics," that paid attention to the interconnectedness between the global ecosystem and economic systems [5, 6]. Under this new field, scholars began to assess the economic value of natural resources such as natural ecosystems and non-polluted oceans, rivers, and atmosphere [7]. "Resource economics" also emerged as another subfield of economics. This subfield incorporates into economic statistics the inventories of natural resources such as water and forests in countries and

H. Imura, *Environmental Systems Studies: A Macroscope for Understanding and Operating Spaceship Earth*, DOI 10.1007/978-4-431-54126-4_8, © Springer Japan 2013

regions, seeks to grasp the material flows associated with economic activities, and attempts to analyze the relationship between the economy and impacts on resources and the environment.

8.1.2 The Branches of Environmental Economics

There are two major streams in economics today: modern economics and Marxian economics [8, 9]. Generally, if the word "economics" is used, modern economics is being referred to. The Earth's size is finite, and the usable resources are also finite. Economics is a discipline that considers how to utilize those finite resources, create value, and distribute that value that has been produced. The resources referred to in economics (i.e., economic resources) include not only natural resources, such as timber and mineral resources, but also all factors that can be mobilized to produce value, including human labor, knowledge and technological knowhow, equipment and facilities, and land.

Neoclassical economics—the foundation upon which modern economics is built—has become a body of theory that excels in its universality and applicability by excluding personal subjectivity or values and instead making extensive use of quantitative analysis. With the collapse of the socialist economic systems of the former Soviet Union and Eastern Bloc countries, the popularity of Marxian economics appears to have faded. Nevertheless, when considering environmental problems, there is still much to learn from Marxian economics and its origins—the works of classical economists such as Adam Smith, Thomas Malthus, and David Ricardo [10].

The Industrial Revolution that occurred in England at the end of the eighteenth century wrought enormous changes in society. Railroads, made possible by the steam engine, enabled the transport of large volumes of goods at great speeds. Machines such as the power loom dramatically boosted industrial production. Industrial towns such as Manchester and Glasgow grew quickly as more and more laborers moved from the countryside to cities to work in factories. Capitalists running the factories became wealthy, but an increasing number of laborers had no choice but to toil under poor working conditions to make a living. The laborers' working and living conditions at that time were poor, and it was common for women and children to labor for long hours. Photographs of England's streets in the nineteenth century show rows of chimneys of coal-burning factories and the backdrop of skies filled with black smoke (Fig. 8.1).

Early economics—in other words, classical economics—was born out of these conditions in England after the Industrial Revolution. Adam Smith published *The Wealth of Nations* in 1776. He argued that through the workings of free competition, the "invisible hand" of the market would bring the greatest wealth, and this argument led to the creation of the intellectual framework for the "laissez-faire" approach to the political economy. In his treaties *Principle on Population* Thomas Malthus discussed the social problems brought about by the finiteness of land resources and

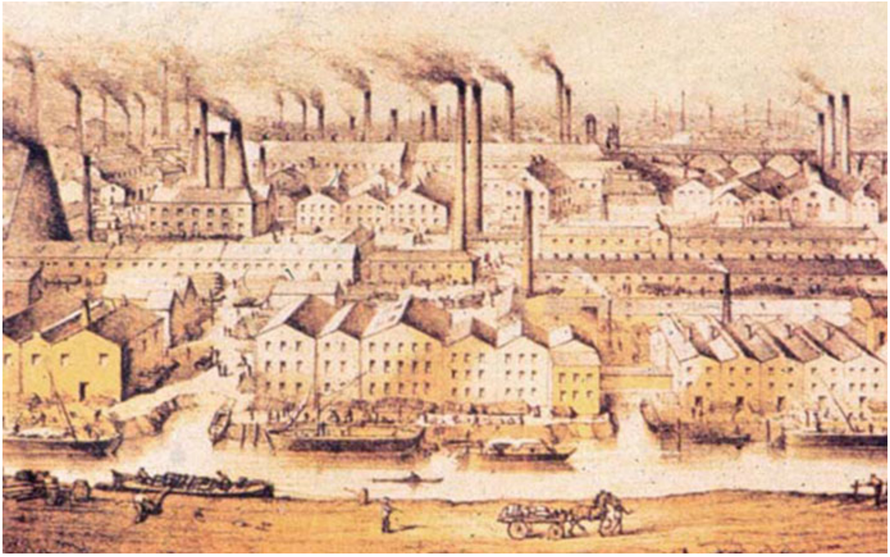


Fig. 8.1 Industrial development in an England city powered by fossil fuel
Source: Picture provided by Nigel Lawson of the University of Manchester

population increases. David Ricardo presented the "labor theory of value," which states that human labor generates value and determines the value of products, and this line of thought continued on in Marxian economics. Malthus's debate provided the starting point for contemporary debate about limits to growth [11].

Today a number of schools and subfields in economics relate to the environment, but a broad view of these reveals two main streams. One starts with neoclassical-type modern economics and incorporates environmental elements into that structure. The other starts with an emphasis on fundamental insights about the value of the environment and the significance of environmental protection. The former, in a sense, is based on the orthodox stream of modern economics, and attempts to incorporate into economics the environmental elements that previously were treated as external diseconomies. In contrast, the latter contends—from a new perspective—with the many problems taken up by eighteenth- and nineteenth-century classical economics and Marxian economics, and from it have emerged a variety of new branches of thought, including "ecological economics" and "entropy economics" [12–17].

8.1.3 Market Failure and Environmental Taxes

The problems of industrial pollution and other forms of pollution that erupted around the world from the 1960s through the 1970s came as a big shock to modern economics. Until then, economists had almost completely ignored industrial pollution, with its attendant damage to human health and ecosystems. The neoclassical school's doctrine was that the market was all powerful to realize the optimal allocation of resources by the price mechanism: efficient distribution of resources was achieved by a balance of the supply and demand of goods being transacted through the market. The problem, however, was that damage from pollution was generated without passing through the market: this is referred to as an external diseconomy. There was not a market in which transaction of polluters and victims take place; polluters dumped pollution, and victims could not do much about it.

Even if it was somewhat unrealistic to believe that the market was all powerful, and that every problem could be solved if left to the regulating functions of the market, the fact that the problem of pollution occurred in the market economy system presented a serious concern. This was a failure of the market, or "market failure." It was as if a weakness in economics had been exposed. Economists suggested that external diseconomies could be incorporated into the economic system, however, with environmental taxes and other tools. The market failure could be corrected and problems resolved within the framework of the market economy. With that, the debate settled down.

When pressed to deal with the issue of industrial pollution, economists were able to contain this theoretical problem within the framework of economics by using the "silver bullet" of environmental taxes. Eventually, however, the scope of debate about environmental problems expanded, and a string of new challenges sprung forth—global warming, the need for compatibility between human activities and ecosystems, the conservation of biodiversity, resource circulation, sustainable development, and other issues. To address these challenges, it was necessary to tackle them at a more profound level—by considering the global climate system, ecosystem mechanisms, resource recycling, and other phenomena—and actively conduct research on these aspects through ecological economics [15, 18]. These subfields of new science, not confined in the narrow span of economics, offered diverse views and deeper insights about the relationships between economic sustainability and the regenerative capacity of a resource known as the environment, and about the value of biodiversity and other topics. Much of the thinking and debate is still at the abstract stage, but it is gradually filtering through society, and in the process influencing humanity's approach toward environmental problems.

Meanwhile, one major strength of modern economics is its effective use of the tools of numerical analysis. Mathematical models and statistics have facilitated quantitative discussions on the economic impacts of global warming and other environmental problems.

8.1.4 Market and Government Failures

The concept of external diseconomies (or "negative externalities") arose from the debate about market failure. We buy what we need on the market, and anything bought and sold on the market has a price. But many things are not bought and sold on the market and therefore have no price attached. Externalities (or "external economies") are positives or benefits that occur outside the market, and conversely, negatives or losses are external diseconomies.

The rise in local property values when a new train station is built is an external economy, but the drop in local property values when a nuisance facility (e.g., a waste incineration plant) is built is an external diseconomy. The loss of a work opportunity when your commuter train is late because of an accident is also an external diseconomy. Market failures associated with environmental protection occur for various reasons. However, one major reason is excessive use of a resource (i.e., the environment) because it is in many cases a free good that anyone can use or access freely, and ownership is not clear, so nobody makes a serious effort to preserve the resource.

Letting livestock eat as much grass as they like in a communal pasture is for the herders an externality. In this case, as suggested in Chap. 7, it is possible to avoid the "tragedy of the commons" by allocating property rights (rights and responsibilities relating to use and management of the commons) to stakeholders. Meanwhile, illness caused by air pollution from a factory is an external diseconomy, but if after negotiations the factory pays the victims compensation for the damages—even if there is some debate about whether or not the amount is fair—the external diseconomy becomes internalized. In other words, what was external to the economy has now been taken into the market in this case. In reality, however, the factories often just continue polluting, and the victims have to pay the price.

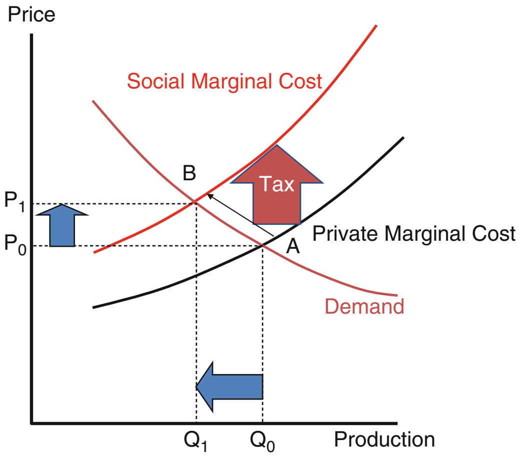
Market failure should not occur if externalities are successfully internalized in the market. Actually, however, another type of failure may occur because of inappropriate government intervention. Self-interested administrators wanting to build their own power will sometimes enact public policies that are popular but not best for the people. Government often operates public enterprises that enjoy a monopoly free from market competition. Government trying to meet conflicting goals often enforces multiple measures that contradict one another. Government failures also arise as a consequence of the illogics of voting. There are many different kinds of government failures as with market failures.

8.1.5 Private Costs and Social Costs

In the market economy, firms generate pollution while trying to maximize profits. An individual's self-interested behavior of driving a car causes traffic congestion and air pollution. Both are negative factors for the economy (external diseconomies), and society is forced to bear extra costs because of them. These are called social costs, a topic studied by economist Karl William Kapp [19]. Hirofumi Uzawa is another economist well known for his work on social costs, including those caused by automobiles [20].

Arthur Cecil Pigou considered social costs to be failures and shortcomings of the market economy, and he developed the foundations of "welfare economics," a branch

Fig. 8.2 Social cost and environmental tax



of economics that addresses ways to resolve these problems within the market economy. As shown in Fig. 8.2, the price and supply of a product will generally be determined at point A, the intersection of the market demand curve and a firm's marginal cost curve. A firm's marginal cost curve typically does not include social costs, so this is called the private marginal cost curve. The social cost curve is produced by adding the social costs on top of the private marginal cost curve. The firm is obtaining unfair profits because it is not bearing the social costs, so normally the price and supply of the product would be at point B, the intersection of the social marginal cost curve and the demand curve. Thus, an environmental tax as envisioned by Pigou would be a tax imposed on a product that is equal to the size of the gap between the social cost and the private cost: this is referred to as a Pigovian tax.

8.1.6 Upstream, Downstream, Polluter Pays or Beneficiary Pays: The Coase Theorem

Water resource management in a river basin involves the overlapping problems of both external economies and diseconomies between regions upstream and downstream. If a forest is well tended in the headwaters upstream, areas downstream will have a stable supply of water to use and damage from flooding will be reduced. Conversely, if the forest upstream is poorly tended, the water storage capacity of the forest upstream will be reduced, and flooding will be more likely to occur downstream. Furthermore, if the areas upstream are cleared, developed, and contribute to water pollution, the areas downstream will not have access to good-quality water.

To manage such a situation, penalties (or surcharges) could be imposed on the polluters upstream. Alternatively, parties downstream could pay parties upstream to have them conserve the headwater forests or stop development that would cause pollution. The first approach follows the polluter pays principle (PPP), and the second, the beneficiary pays principle (BPP). Another approach is the victim pays principle.

Economist Ronald Coase presented the argument that whether the PPP or BPP approach is taken, the effect (the level of welfare) will be the same for society as a whole (the total of all effects on the polluters and the victims) [21]. This view was labeled the Coase theorem. The best method for society to choose depends on which one is easiest for stakeholders to accept. This argument is not valid, however, in cases where extra time or costs (transaction costs) are required to reach consensus or negotiate among the parties.

Many airborne pollutants are carried on the wind to Japan from China, including yellow dust from arid regions in western China and photochemical smog. If these countries were to follow the polluter pays principle, Japan would demand that China pay its own costs for preventive countermeasures. Because Japan was the more prosperous of the two, however, the most realistic solution was for Japan to provide assistance to China to carry out the countermeasures. This could be an example of the victim pays principle. On the other hand, if China becomes prosperous enough from economic growth, the structure of negotiations could be expected to change in the future.

8.1.7 What Is the Value of the Environment?

Society generally accepts that the environment is important, should be protected, and has value. This brings us to a big question: What is the *value* of the environment? Three main approaches can help us consider this question. The first approach recognizes that the environment itself has intrinsic value. This way of thinking is associated with ecocentrism, discussed in Chap. 6, and one could say it is close to being a set of values, almost of a religious nature. Another way of saying this is simply to assert that all life on Earth is inherently precious, without forcing a discussion on the economic value of biodiversity, ecosystems, and nature.

The second approach attempts to assess the environment for its utility value as a resource. This is the approach of modern economics, itself based on anthropocentrism. It is important to note that much of the value obtained from environmental resources is in fact the effect of external economies (or external diseconomies avoided) and cannot be directly measured by market prices. Thus, for example, if air and water pollution result in damage to the health of victims, economists could attempt to measure the value of *unpolluted* air and water based on the avoided medical costs of treating victims, based on the reasoning that pollution causes the living environment to deteriorate. Similarly, the value of forests could be assessed from the capacity of the forest to recharge the water supply and provide water resources, the avoided costs of flood damage prevented by a forest's water conservation capacity, the revenues from forests as a tourism resource and source of amenities, and other service functions [14]. Attempts have also been made to calculate the value of biodiversity based on the potential for new drug development from the materials extracted from wild plants and animals for Eastern medicine, and other benefits.

The third approach is to assess value from the perspectives of ecological economics and entropy economics. These schools of thought assert that the monetary value of the environment is not something to be debated directly, and that the focus of attention should be on the importance of the ecological functions fulfilled by resource circulation on Earth. The global ecosystem, based on plant photosynthesis and the circulation of air and water, already has sustainable cycles of material circulation. Entropy economics asserts that humanity must create economic systems that do not disrupt the material circulation of nature. This line of discussion is producing a growing number of assessments of the negative aspects of current industrial production systems that are not compatible with the global ecosystem. This line of reasoning is similar to Marxian economics, in that it critically identifies the flaws of capitalism but does little to contribute to economic management in practice.

8.1.8 What About Future Generations?

In the context of assessing the utility value of resources under the second approach just described, a question often asked is this: How should society today consider value for future generations? This question is similar to an investment question. What is the difference in value between a million yen today and a million yen that can only be used in the future, as in the case of a bank term deposit that cannot be cashed before maturity?

If an annual interest rate of 5% is paid on a term deposit of $1,000 starting today, in 10 years it will be worth nearly $1,630: this means that $1,000 today and the approximately $1,630 in 10 years have the same value. Conversely, we can interpret this as meaning that the future $1,000 is only worth about $610 today in present value. This method of evaluating discounts the future value, but how should the discount rate be determined?

The discount rate is critical when discussing long-term issues. If it is too big, the future value (or damage being considered) will be assessed too low, and this effectively means neglecting or ignoring the distant future. In ecological economics, some scholars reject the very concept of the discount rate. Others say that it should be set as closest to zero.

8.2 Environmental Economics and Environmental Policy

8.2.1 Environmental Information and Consumer Behavior

When we desire or want to purchase a product, it is because we expect some kind of satisfaction from that product. In economics this is referred to as utility. Consumers, under budget constraints, tend to behave in a way that maximizes utility, using product price as the signal. When intending to select a certain product, a consumer has a variety of thoughts interacting in the mind. Behind our consumer behavior a variety of factors are at work, one of which might be consideration of environmental impacts, and consumers weigh these all in an integrated way when deciding whether to buy a particular product at a particular price.

How is the price of the environment reflected in consumer utility? Consider products A and B, which have exactly the same functions but are priced differently. Product A is priced high because environmental considerations are adequately incorporated into its designs and production process, while product B is produced with no environmental consideration, resulting in a low price. Which product will a consumer choose? Common sense might suggest that the choice would be for the lower-priced product B. In this case, it would mean that consumer is not aware that the higher price is required for environmental measures of Product A, and as a result selects the cheaper product.

Regarding environmental considerations in the product, if the same regulations apply to all manufacturers, and the manufacturers observe the regulations to the same standard, it would be rational for the consumer's selection behavior to favor a cheaper product. In some cases, however, manufacturers may have voluntarily undertaken a variety of environmental measures, having tuned in to a consumer preference for environmental protection. In that case, if detailed product information is provided, consumers with an interest in environmental protection might select the environment-friendly product even if the price is higher.

How can anyone determine how environmentally friendly a product is? One method to answer this question is a life-cycle assessment (LCA), described in more detail in Chap. 9. This method attempts to assess the environmental impacts embodied in a product, based on the resource inputs, pollutants, and waste generated during the life of the product, through production, use, and disposal—from the "cradle to the grave."

8.2.2 Green Gross Domestic Product and Attempts to Measure Happiness

If the economy is strong, products sell well, wages and bonuses increase, and people feel more prosperous. Various indicators are used to judge economic conditions—including the jobless rate, consumer prices, machinery orders received, and other indicators—but gross domestic product (GDP) is still used as the most important index today.

Debate began in the 1970s to challenge the idea that GDP is really the true measure of the well-being or happiness of citizens. Japan's economic growth rate was high at the time, but the damage from industrial pollution and deterioration of the natural environment made people begin to feel that there was a disconnect between the numbers and the feeling of quality of life. Scholars began to consider what became known as "green GDP," which incorporates environmental value into the index.

A country's GDP is ultimately a measure of the total of goods and services produced in its economy. Production requires the inputs of various factors, including labor, capital (including civil infrastructures, factories, equipment and facilities), land, mineral resources, and others, but resources such as air, water, and nature are almost completely overlooked in typical economic indicators. When a product is produced, its value is calculated as a part of the GDP, but any pollution or damage caused by the production process is ignored. Economic statistics today do not calculate the hardship suffered by pollution victims, but do count the increase in GDP caused by the payment of a victim's medical treatment costs. Many feel that this omission is not right. Meanwhile, nature (biodiversity, ecosystems, etc.) surviving in a country generates a variety of environmental services, although their benefits are ignored in GDP calculations.

Since the early 1990s Japan's economic growth has been relatively stagnant, and the government has done all it can to increase the GDP itself. It seems that the debate about a green GDP has lost some momentum. On the other hand, some progress is being made with discussions about environmental taxes—which attach a value to the environment, formerly treated as a free good—and the introduction of emissions trading. If ownership and prices were attached to the good we know as the environment, then the value of that good would be incorporated into the GDP.

8.2.3 Smart Policy Selection

Environmental management can be broadly classified by type of approach: command and control approaches through legislation, economic approaches through market mechanisms, and voluntary approaches by firms, consumers, and other entities. The following criteria are useful when comparing and selecting a policy measure for environmental management:

1. Effectiveness: Will it achieve objectives for environmental improvement or conservation?
2. Efficiency: Is it cost-effective? If different options will achieve the same objective, the least-cost option is desirable.
3. Equity: Who will benefit and who will bear the costs? Is the allocation of costs and benefits fair for stakeholders?
4. Administrative and transaction costs: Are the personnel and organizational costs for implementation reasonable? Will the time and effort required to achieve consensus among stakeholders be reasonable?
5. Long-term results (dynamic efficiency): Even if there are short-term costs, what will be the long-term results through new technological development and innovation? The long-term benefits should be considered.
6. Social acceptance: Can the measure gain the support and agreement of stakeholders (voters, local community people, corporations, etc.)?

Whichever policy measure is selected, it is important to analyze its effects. A major element in that review will be analysis of the economic costs and benefits. Such a review should also incorporate ways to assess virtual value, because the environment may not necessarily be assessed in terms of market value. For example, because no market attaches an explicit price to the value of beautiful scenery, comfortable cities, or pure air, some assessments determine value from the price people are willing to pay (WTP), travel costs, and other survey data.

8.2.4 Equity: Fairness Between Regions, Generations

Ultimately, much of the conflict of opinion that arises relating to environmental issues comes from the issue of equity—different views on fairness in the distribution of profits and allocation of costs. With a local commons, the resolution of differences is achieved in some cases according to the rule of law, through mediation, or a court decision based on national legislation. For the global commons, however, humanity does not yet have an effective system to handle matters of this sort.

The reality of the global commons raises major issues in terms of inter-regional and inter-generational equity. Some developing countries have expressed the view that developed countries are the main cause of today's global environmental problems, and therefore they oppose any restrictions of their own right to develop themselves. Furthermore, the problems caused by current generations will ultimately be left behind as a negative legacy or debt that may obstruct future generations' potential development, even though they have no opportunity to express their views about policy decisions today.

The legal concept of justice includes concepts of equity and fairness, but ethical judgment of this sort is not addressed openly in economics. For example, the public tends to interpret the polluter pays principle with the ethical nuance that the polluter is in the wrong and should therefore compensate the victim for damages. In economics, on the other hand, the interpretation is simply that for the economy it is most efficient for the polluter to bear the social cost of pollution.

8.2.5 Greenhouse Gas Emissions Trading

Under the Kyoto Protocol, to prevent global warming, national targets were established for developed countries' annual greenhouse gas (GHG) emissions. The targets were for a reduction by 2010 compared to emissions in 1990 (e.g., 8% for the United States, 7% for the European Union, and 6% for Japan), but the United States subsequently withdrew from the Protocol, and it is not certain whether the European Union and Japan have achieved their targets (as of June 2012).

The fact that emission amounts were settled upon effectively means that permission is required to emit that amount of GHG emissions into the atmosphere. If a large number of entities tried to obtain permission, however, the result would be mass confusion. To solve this problem, various ideas were proposed, including the use of emission permits and emission rights that could be traded on the market. This concept is referred to as "cap and trade," because a total (cap) is set for emissions, and then the rights to emit are traded.

The city of Shanghai in China imposed a certain limit on the number of car license plates it issued to prevent a rapid increase in the number of private automobiles on the road. Now, anyone wishing to buy an automobile must compete with others to get a license in the auction market. This stratagem looks very similar to a cap-and-trade system.

The initial allocation is the most difficult problem faced when issuing emission permits or allocating emission rights. Because many entities already emit GHGs, the question is how to deal with existing emitters and with new emitters. One way to resolve this problem would be to issue emission permits or emission rights to existing emitters for their current emissions, but this would give an advantage to those parties who have not made an effort to reduce their emissions until now and a disadvantage to those who have already made an effort. Thus, such an approach would not be equitable. Exactly the same problem arose when establishing the national emission targets for the Kyoto Protocol. Indeed, the Japanese government claimed that Japan ended up with a disadvantageous agreement because it had already made strenuous efforts for energy conservation during the 1970s and 1980s before the protocol was put into force.

Discussions are now actively underway both internationally and domestically to create detailed framework designs for GHG emissions trading. Sales have already begun of carbon credits—a product that represents the GHG emission reductions achieved by an entity's own efforts. For example, if a company replaces its old equipment with new, more efficient equipment, and thereby reduces its GHG emissions, it is able to sell credits for that amount of reduction. Conversely, corporations that expect to increase their GHG emissions along with increased production are able to purchase these credits. This framework is not for emission rights or emission permits, but because it involves the trading of emissions achieved or expected (emission units), it is referred to as emissions trading.

Emissions trading is an attractive system that can bring in revenues in the event of successful efforts to reduce GHG emissions, but for the system to function, it is important to be able to show that the assessment of reductions can be trusted. Thus, besides establishing markets to trade credits, it is also necessary to establish systems to audit and verify the credits. Within the European Union region, a GHG emissions trading scheme (The European Union Emission Trading Scheme, or EU ETS) is already operating. In Japan, the Tokyo metropolitan government has introduced its emissions trading [22].

8.2.6 Environmental Macroeconomics: Thinking the Environmental Implications of Environmental Policies

Environmental policy such as emissions regulations and global warming countermeasures generally involves new expenditures, which may slow economic growth in the short term. It is therefore not unusual for environmental policies to be opposed by those who emphasize the possible negative impacts on the economy, although environmental policies can also actually have positive impacts on the macro-economy in the long term through technological innovation and structural transformations in society and the economy. As for the economic impacts of global warming countermeasures, research teams around the world have conducted studies using simulations with macroeconomic models to make predictions; such studies form the basis for some analyses in Intergovernmental Panel on Climate Change (IPCC) reports on future scenarios of countermeasures and their effectiveness. Meanwhile, upon request by the British government, economist Nicholas Stern (formerly Senior Vice-President of the World Bank) prepared the "Stern Review on the Economics of Climate Change" (released in October 2006) [23].

Often referred to as the Stern review, this report frankly discusses the uncertainty and difficulty of making future projections on the economy and environment, examines the risk that the damage from global warming could be more serious than being predicted at the time, and concludes that the best strategy would be to take immediate and decisive action. It states that to avoid the most severe impacts of global warming, it is necessary to limit GHG concentrations (counting all GHGs, converted to carbon dioxide equivalent), currently at about 430 ppm, to between 500 and 550 ppm, and that to do that, annual GHG emissions must be cut from current levels by 25% by 2050. The "Stern Review" presents the view that with annual expenditures of about 1% of GDP, it would be possible to achieve these reductions while maintaining economic growth.

The report state that, as specific measures, emissions trading should be implemented, low-carbon and highly efficient technologies need to be developed, forest logging should be banned, and so on, but even when the costs of such measures are counted, sustainable economic growth would still be achieved. If one assumes that the world GDP in 2050 will be about three or four times the current level, GHG emissions per unit of GDP must drop to about one quarter of current levels. Meanwhile, there are concerns that if temperatures rise by 5°C or 6°C because of global warming, the damage could exceed 5% of world GDP, and if we consider risks and impacts more broadly, losses could reach 20% of GDP. If it were possible to avoid this scale of damage by spending about 1% of GDP per year, the wisest choice would be to carry out the countermeasures.

8.2.7 Seeking for Win–Win Approaches

Human activity in modern society is often considered only in relationship to economic activity. In contrast to our self-sufficiency in primeval times by gathering what we needed from nature, human behavior in modern society is all incorporated into the market economy system, which runs on money in many aspects of our lives. Economic activity produces wealth when we gather resources from the natural world, processing the material with human labor and technology to produce a good that has added value, exchange the good for other goods produced, and consume them. It is through the adjustment of supply and demand through prices—in other words, the market—that this economic activity is most efficiently controlled.

The market is not all powerful, however, and it can be argued that a variety of problems in the world are the result of market failure. A typical problem is the excessive consumption of resources or the deterioration of resources, which can be traced to the fact that environmental resources such as air, water, and soil can easily be used by anyone as free goods or almost nearly for free. Pollution of air and water are typical examples of these dynamics. We could say that one role of environmental management is to control, by various measures, the use of environmental resources that previously have been treated as free goods. There are two typical methods: attaching prices to the environment by imposing taxes or levies, and creating a market to trade environmental resources.

Environment problems and the economy are inextricably connected. If the economy slows, the purchase desire of individuals weakens, the consumption of energy and resources declines, and the burden on the environment is reduced. This reduced burden is something desirable for the environment, but other consequences are less desirable. People may see their own incomes decline, and may even risk losing their jobs. The welfare of society could decline, and public safety may worsen. If all this happens, a nation's top priority would be to somehow revitalize the economy, stimulate consumer purchasing, and make various attempts to restore consumption to higher levels. This is the nature of the balance, or imbalance, between the economy and the environment today.

The important thing now is to choose a desirable path for both the economy and environment. For this, we need a shift in demand toward products and services that are good for the environment. If oil prices stayed at high levels, the worldwide use of solar energy and biofuels would increase; these energy sources have not yet grown to their potential because their costs are high compared to the price of fossil fuels. It is therefore desirable to raise the price of oil, at a rate that does not cause sudden disruptions in the economy, to promote more rational use of that scarce resource, and also as a measure against global warming. Economies always experience repeat cycles of growth and recession. The key challenge is to invest in the environment even when the economy is in recession, with an eye to the future.

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Chapter 9
Resources, Energy, and Environmental Load

9.1 Economic Activity, Resources, and Energy

9.1.1 Resource Productivity, Energy Productivity

Industrial activity today requires the inputs of enormous amounts of natural resources, including metals, timber, oil, stone, gravel, and other minerals. In 2004, Japan's nominal gross domestic product (GDP) was 570 trillion yen, matched by natural resource inputs totaling 1.7 billion tons: this signifies 336,000 yen of GDP per ton of natural resource inputs. This measure is referred to as "resource productivity," and the national government's Basic Plan for Establishing a Sound Material-Cycle Society includes the target of raising this to about 420,000 yen in 2015. Meanwhile, in terms of energy, Japan's primary energy supply was 562 million tons (oil equivalent), which means that Japan produced about 1 million yen of GDP per ton of oil equivalent energy input. This measure is referred to as "energy productivity." Both resource productivity and energy productivity are improving; compared to 1975, the former has improved by a factor of 2.0 and the latter by a factor of 1.4 [1].

9.1.2 Visible and Hidden Resource Flows

Resources come in many types of value. Diamonds and rare metals have very high value in a small volume, whereas materials such as gravel are bulky and less valuable. Rare metals, including rare earth metals, are used in electronic products, and even small quantities have tremendous importance in the workings of electronic technology.

Resources covered by economic statistics and analysis concern only those items that are priced and traded on the market. In the case of rocks and gravel, only the quantities used as construction material are included in economic

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indicators, although enormous amounts of soil, rock, and gravel are moved about at construction sites and through the extraction of buried resources at mines. Material flows traded in the economy are considered “visible flows,” but resource inputs not recorded in economic statistics are referred to as “hidden flows” [1]. Examples include the soil excavated at construction sites, the rubble and tailings at mining sites, soil eroded from cultivated land, and trees cut down but not harvested as timber in logging operations. These hidden flows have also been called “ecological rucksacks.”

For every ton of coal mined, it is necessary to move about 4.9 tons of dirt and rock. For 1 ton of iron, the figure is 5.2 tons, and for copper it is 450 tons. To extract 100 g of gold, 95 tons of dirt and rock must be moved. The reason that rare metals such as gold and platinum are so expensive is that they do not exist in abundance, and also that these hidden flows are reflected in the price. In the case of rare metals, the price reflects both the rarity of supply and the difficulty of extraction. It is fascinating to analyze the relationship between the price of elements and the amount of effort required to extract an element from the environment, or the relationship between price and entropy transformation [2].

9.1.3 Embodied Energy

When a product is manufactured, energy is used as an input into a variety of processes, including raw material extraction, production at the factory, and transport. If we change our perspective, we can consider the energy incorporated into a product or service to include not only the direct energy input to produce and provide the product or service to the market, but also the energy incorporated indirectly through intermediate material inputs. This concept is referred to as “embodied energy” and is sometimes also called “life cycle energy” [3].

The inverse of energy productivity indicates how much energy (tons of oil equivalent) is embodied per million yen of GDP. Table 9.1 shows more detail, based on an industry sector-by-sector analysis using input–output tables. Figures were obtained for 399 industry sectors for the input–output table used, and the same value was applied to different products produced in the same industry sector [4]. As a ballpark figure, a purchase worth 1 million yen (or about 12,000 U.S. dollars) involves the energy consumption of about 1 ton of oil equivalent, and about 2.3 tons of carbon dioxide emissions (or 1 kg oil equivalent of energy and 2.3 kg carbon dioxide per 1,000 yen). Envisioning carbon dioxide in its form as dry ice is a useful way to imagine it.

If we now consider food, the amount of energy consumed at various stages before the food enters our mouths is several times the amount of food calories we take into our bodies. For example, fuel is consumed by cultivation equipment, tractors, and fishing boats, and it is also consumed during refrigeration and canning processes, transportation, distribution, and even refrigeration and cooking at home.

Table 9.1 Environmental impacts per unit monetary output, calculated from input–output tables (selected examples)

		Energy (kg oil equivalent per thousand yen)	Carbon dioxide (kg-CO_2 per thousand yen)
Farm crops, food items	Rice	0.52	1.45
	Beef cattle	0.71	1.96
	Sea fisheries	3.02	8.81
	Frozen seafood	1.85	5.29
Consumer durables	Automobiles	0.94	2.77
	Television receivers	0.71	1.93
	Household appliances	0.83	2.37
Basic materials	Cement	13.16	110.64
	Crude steel (blast furnace)	11.45	47.60
	Crude steel (electric furnace)	3.90	14.23
	Copper	1.77	5.17
	Petroleum products	1.92	4.46
Construction	Housing construction (wood frame)	0.63	1.96
	Road transport-related public works	0.99	3.74
Service	Retail	0.49	1.27
	Financial	0.18	0.46
	General food and beverage	0.72	1.91
Transport	Passenger rail transport	0.82	2.19
	Road freight transport	1.44	4.04
	Air transport	4.02	11.05

Source: Prepared by author based on data from Nansai et al., National Institute for Environmental Studies (NIES) of Japan
Note: This table shows the results of calculating the kilograms of oil equivalent as energy input, and the number of kilograms of carbon dioxide emitted, per thousand yen of final demand in each industry, based on figures from Japan's 1995 industrial input–output tables (399 categories). Conversion for physical quantities can be done by applying these figures to product unit price. The same figures are applied to all products produced in the same industry, even if a different product. Although there are some differences depending on the item, average is about 1 kg oil equivalent of energy input per thousand yen, and about 3 kg carbon dioxide emitted per thousand yen. Envisioning dry ice is a useful way to understand carbon dioxide through direct experience

When we attempt to reduce energy consumption, we have a tendency to focus only on the visible direct energy consumption, but all consumption activities, whether related to clothing, food, housing, or whatever, can consume energy indirectly in the form of embodied energy. This awareness of embodied environmental loads can also be applied to items other than energy, such as water resources, total material input, and other resource inputs, and is very important to help understand the meaning of life-cycle assessments (LCAs), as discussed below.

It is worth noting that Marxian economics use the labor theory of value, which states that the price of a manufactured product represents the human labor embodied in the product. Labor, in physics terms, is referred to as "work"; the energy source for human labor is food, which is itself solar energy that has been transformed [5]. Today, however, energy as an input into production is more a matter of machines than human labor; thus, the proportion of energy input from fossil fuels is overwhelmingly larger than from humans. This is also why, in our economy today, the price of products is very much affected by the amount of fossil fuels used in their production.

9.1.4 Resource and Energy Flows Associated with Human Activities

A variety of materials are consumed each day to support the survival and activities of the average person in Japan today: 1.4 kg of food, 320 l of water, and the equivalent of 2.4 kg oil equivalent of energy (oil equivalent: total includes household energy use and automobile use; figures as of 2000). As a result, a variety of waste and pollutants are generated each day: 1.1 kg of garbage (municipal waste), 320 l of wastewater, and carbon dioxide amounting to the equivalent of 8.8 kg of dry ice.

These figures represent the resources and energy associated with direct consumption by individuals, but in addition to these amounts, energy is also consumed by industrial and commercial activities. Ultimately all these activities are being carried out in support of the human economic activities to make our affluent lifestyles possible, so it would be fair to consider the consumption from industrial and commercial activities as consumption on behalf of individuals. Including all those numbers would result in quite a large figure per person: daily carbon dioxide emission amounting to the equivalent of 30 kg of dry ice or about half of our body weight.

To protect the environment, individuals must get a grasp on the quantitative amounts of resources and energy they consume, as well as the environmental loads generated by their consumption. Then, by making improvements in their lifestyles, they must continue making efforts to actually achieve the reductions wherever possible. Environmental accounting of households and firms is one way to help attain a quantitative grasp of the situation.

9.1.5 Urban Activities and Resource Circulation

Today about 70–80% of the population in developed countries lives in cities, and developing countries are urbanizing rapidly as well. The future of the Earth will depend on the future of cities. It is clear that if we are to make our societies on Earth sustainable, we must make our cities sustainable. Cities are places many people gather to live and engage in economic activities. Cities take in vast amounts of resources to sustain those activities and then discharge into the environment

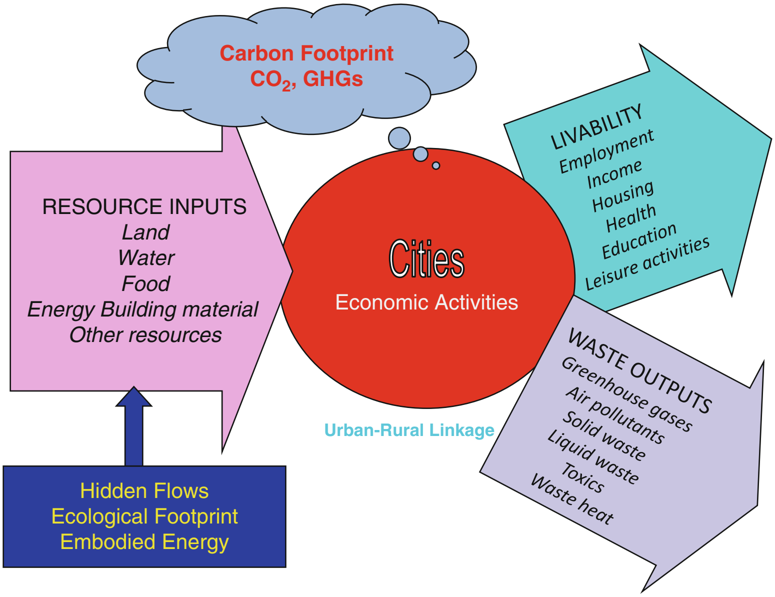

Fig. 9.1 Cities as ecosystems
Source: Prepared by the aouthor after Peter Newman & Jefferey Kenworthy

(atmosphere, water, and soil) the vast amounts of waste generated through those activities. In this sense, cities are like ecosystems as demonstrated in Fig. 9.1.

If a city's scale of activities becomes too large, then material and energy cycles cease to function properly, constraining the city's further economic growth and causing a variety of environmental problems. This situation resembles the city having poor blood circulation, similar to a blockage of the blood vessels. Therefore, the flows of resources and energy, as well as the amount of waste generated from these flows, are important indicators for the environmental impacts of urban activities on the environment [6, 7].

The physical components of a city include housing and commercial buildings as well as roads and other forms of infrastructure. Activities in a city include the vast flows of people, goods and materials, energy, and information. Thus, the inside of a city is like the mesh of a network—roads, rails, water and sewer lines, electrical and gas grids, and communications lines.

These networks, if compared to the human body, are similar to the networks of blood vessels and nerves: the equivalent to blood and nerve signals flowing through the system would be materials, energy, and information. The arterial blood flowing from the lungs circulates through the body and picks up waste matter from each part of the body as it becomes venous blood. In the body, the liver, kidneys, and other organs are charged with the role of processing the waste matter. The equivalent in a city would be the environmental facilities such as water purification plants, sewage treatment plants and garbage treatment facilities.

9.1.6 Ecological Footprint

To sustain those activities, those within cities depend heavily upon resources from outside. Much of the food ingested by city residents is transported from outside the city (as illustrated in Fig. 9.1). Enormous amounts of soil, water, fertilizers, chemicals, equipment and machines, and fuel are consumed to support the affluent food habits of urban citizens. Canadian economist William Rees proposed the concept "ecological footprint" to represent the total land required to supply the food and timber products used in a city, in addition to the forest land needed to absorb the carbon dioxide generated by the city [8].

The area of London is 1,580 km^2. Some researchers found the city's ecological footprint to be an amazing 125 times that figure, equivalent to 80% of the total land area of England [9]. The result for Tokyo and other Japanese cities is roughly similar. Japan imports almost half of its food from overseas, and uses an enormous amount of land, water, and other resources overseas to produce its food and timber.

9.1.7 Transportation, Environmental Burden, and Compact Cities

Mobility, or freedom of movement, is a basic human demand. Thus, the number of cars on the road is increasing rapidly, even in developing countries with relatively low per-capita incomes. As cities spread out and cover more land area, it is necessary to connect areas within cities to each other, and also cities to other cities, via efficient and rapid transport systems. To this end, many cities in Europe and North America developed networks of subways, trams, and buses, starting at the end of the nineteenth century. During the twentieth century, however, with the rise of the automobile, cities were created that depended completely on personal car transport—and they are characterized by having lower population density and being decentralized [10].

Thus, transport is a critical topic to create cities with low environmental impacts. First, innovative automotive technologies must be developed to dramatically improve fuel economy. Second, there should be a shift away from the use of private cars in favor of public transport. Third, cities themselves must be redesigned to increase the efficiency of energy use—including not only transport systems but also land use, city layout, and citizen lifestyles. Partly in response to the shrinking population and the aging of society, local cities in Japan are moving toward compact-city designs that involve less horizontal movement. They are doing this by zoning for taller buildings and concentrating more land uses into the city center that were previously allowed to spread into the suburbs without any master plan. The city of Aomori in northern Japan is one such example where new approaches to planning are being used.

Older cities in Europe are also trending toward compact-city designs, bringing back tram systems and introducing new light rail transit (LRT) systems. Meanwhile, the urban planning trend in younger cities in developing countries is still to promote car dependency. Some cities are expanding without any clear vision of urban development, and even though their road infrastructure is already inadequate, the number of cars on the road is increasing rapidly. Without a change in course, energy consumption and carbon dioxide emissions can only increase.

9.1.8 Environmental Resource Accounting and Material Flow Analysis

The variety of things traded as economic goods are actually natural resources that have been transformed, so we could say that natural resources are the ultimate source of economic activities. Despite that, modern economic statistics incorporate virtually no data about natural resources. To rectify this, efforts are being made to incorporate accounting for natural resources into the system of national accounts (SNA), which provides economic statistics; discussions are underway about how to incorporate statistics on the stocks and flows of natural resources, including forests, soil, water, air, biodiversity, and other environmental elements. Known as natural resource accounting, this is closely connected with "green GDP" [11]. With these kinds of statistics, we can expect that together with regular reporting on economic activities we will also have access to statistics on the loss of forests, changes in quantity and quality of water resources, changes in air pollution, degradation of soil, and so on. At the moment, however, this work is still at the research stage in many countries and international organizations [12–14].

The Japanese government [1] has announced national targets for resource productivity, and research is actively being conducted into material flow analysis (MFA), which analyzes resource inputs into and outputs from economic activities. Conventional MFA has paid attention to material quantities, but there are limitations to assessments based on quantity alone. For example, some dioxins are extremely toxic, even in miniscule amounts. For this reason, research is being conducted focusing on the properties of substances.

9.2 Life-Cycle Assessment

9.2.1 What Is an "Environmentally Friendly" Product?

In recent years, people often see products that advertisers claim are environmentally friendly, or eco-friendly. Let us consider what "environmentally friendly" really means. Some brands of household appliances on the market—televisions and air conditioners, for example—consume less electricity, and in effect emit fewer carbon dioxide emissions, while offering the same features and functions as other products. However, many consumers pay more attention to the price than to these claims. A salesperson at an appliance shop may tell a customer that even though a certain product is more expensive than another, the customer will save on electricity charges because the product is energy efficient and thus in the end is a better deal.

If we wish to consider whether the product purchased is truly environmentally friendly, we should consider not only it usage at home, but also whether the factory polluted the air and water in the product's manufacturing process. Going even further, we would also have to consider the parts and raw materials used in the product, because pollution has been discharged through the mining, extraction, transport, and refining processes associated with the iron, copper, aluminum, and other metals in the product.

The question of whether something is environmentally friendly is not just a problem relating to individual products. There are many problems relating to technological systems that support society. For example, which is better: a highway or a railroad? A densely planned city with tall buildings or a decentralized city with many single-family homes? Waste incineration or material recycle of waste? Actually, because of a lack of clear assessment yardsticks to compare such alternatives, in many cases the conclusion will differ, depending on the method of analysis and assessment. Let us consider this problem now, by examining the idea of a LCA, developed to assess the environmental performance of products.

9.2.2 LCA of Products

A LCA, stated simply, is a way to assess the total environmental impacts of a product over its entire life, "from the cradle to the grave." For a given product, it involves all stages from the resource extraction through product manufacturing, transport, use, and disposal, conducts a quantitative assessment of the environmental impacts generated and interpret their implications for the local and global environment and ecosystems. For manufacturing processes, the calculation of environmental burden includes the mining and extraction of raw materials for making the product, as well as their transport, and the manufacturing of equipment and facilities used in manufacturing processes at the factory [15–18].

For products, in principle, the assessment is to enable the comparison of items that offer similar functions and services. For example, for a consumer good or consumer durable, such as a television, for instance, a comparison might be made between an LCD screen and plasma display of the same size; for automobiles, it might be between a gasoline-powered car and a hybrid car of the same size. For product LCAs, this point should be strictly observed. Similar products providing a certain equivalent service must be compared. It would be difficult to make a comparison if the functions are completely different, for example, as comparing a television and a car.

Environmental household accounting systems have also been developed to record the items purchased and money spent for them and to analyze the environmental impact caused by consumer behavior of individuals. In this accounting system, LCA data can be incorporated for various commodities and wastes. If manufacturers were to publish data about many products, individuals would be able to better assess the products they have bought.

9.2.3 To What Can LCA Be Applied?

As a pioneering example of LCA, the Coca-Cola Company conducted an assessment when plastic bottles made from polyethylene terephthalate (PET) first appeared on the market in 1969. This was a comparative analysis to determine which was better—a returnable glass bottle, or a throwaway PET bottle. It was in 1991 that LCA came into broader use, and this was because the International Organization for Standardization (ISO) began work to consider the topic. The ISO's focus in the area of LCA is on products, and it has produced agreed-upon guidelines for ensuring that information is objective and standardized, to facilitate comparisons of data from different countries and corporations [13, 14].

The principle of comparing items that offer the same functions and services is important to ensure that evaluations are objective, but there is a gray zone in their definition. For example, a comparison of wine and beer is not entirely impossible for the same amount of alcohol, but it would not be possible to compare differences in strength and taste. Meanwhile, there is much demand for comparisons of the environmental friendliness of technological systems. Examples of such comparisons might be between an aircraft and a high-speed train for a roundtrip between Paris and London, or the comparison between a coal-fired thermal power plant and a nuclear power plant. Furthermore, other themes to study in the future include assessments to provide input when improving urban infrastructure and facilities, such as roads, rail, and waterworks. These assessments might cover the total burden on the environment from present to the future, including construction and transport, maintenance, and operation.

9.2.4 Life-Cycle Inventory Analysis

The first step of an LCA is a life cycle inventory analysis, which is concerned mainly with the work of gathering and calculating concrete data. Data are collected about the resource and energy inputs associated with the manufacturing, use, and disposal stages of the target product, as well as the product produced and waste emitted, and then a type of input–output table is prepared relating to resources and environmental burden (Fig. 9.2).

The conventional way to do this is the bottom-up method, which involves calculations after listing all the details on the parts, materials, and manufacturing processes. The question of how much detail to pursue for each item depends on the level of detail obtainable in data for each item. There are certain limits on the extent of what can be determined by this method, so a country's input–output tables are

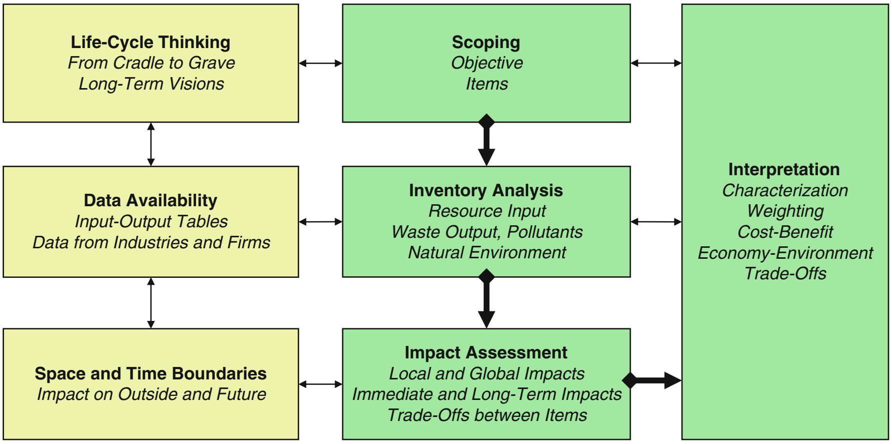

Fig. 9.2 Conceptual flow of a life-cycle assessment

often used in tandem. If input–output tables are used, however, the number of classifications of items is limited to the number of sectors in the input–output tables (about 400 for Japan), because all products produced in a certain industry will be treated in the same way.

After the inventory analysis, the next step is a life cycle impact assessment, which is an analysis and assessment of the size and importance of each impact, based on the inventory analysis data, for each separate category of environmental impact (for example, global warming, air pollution and eutrophication).

Finally, the foregoing results are evaluated, interpreted, and summarized in a report, in a form that is compatible with the original objectives and scope of study, and then a critical review is conducted to confirm whether the adopted methodology and data are reasonable and scientifically valid.

9.2.5 Life Cycle Impact Assessment

In reality, LCAs in many cases do not go beyond the inventory analysis stage, because no absolutely reliable method yet exists for impact assessment. Actually, this is not only a problem with product LCAs, and in fact is the cause of confusion and debate about the comparison of various technology systems, so let us discuss this in more detail.

There are many types of environmental impacts. Some are global and affect the entire world, such as global warming and ozone depletion. Others are on a regional scale spanning several countries or an entire continent, such as acid rain. Still others are relatively confined to a certain area, such as air pollution in a city, or eutrophication of a river or lake. Even if the focus is on just one product, the impacts are broad and deep, and it would be extremely difficult to provide a definitive answer to the question about the priorities, for example global problems or localized problems. The category of greenhouse gases includes not only the much-discussed carbon dioxide, but also other substances. For instance, chlorofluorocarbons (CFCs) are not only ozone-depleting substances but also a cause of global warming. Thus, a proper impact assessment should be developed to address such complex relationships. Discussions are still underway on many points such as this, but the framework for analysis is generally moving in the direction explained below.

The first is a classification according to the type of environmental impact—global warming, ozone layer depletion, local air pollution, eutrophication, and other issues. The second is characterization of each classified environmental impact—an assessment of the relative importance and role of each emission. For example, in the case of global warming, it is possible to evaluate the roles of various greenhouse gases in relationship to their global warming potential (GWP), which is the strength of the greenhouse effect based on molecular structure. In the case of eutrophication, there is an assessment method available using algal growth factor (AGF). The third is an integrated assessment using a system of weighting of different impacts.

Regarding the final point, weighting, there are attempts to develop an indicator to evaluate problems that are completely different in character and in detail, and this issue presents some difficult questions. For example, there is the question of whether it is possible to summarize in a single indicator the importance of meat, rice, and vegetables as food. An initiative is underway to decide on priority levels using questionnaire surveys on public perception on the relative importance and weight of different environmental factors, but there is still much debate about how far this can be satisfied.

In Japan, the Industrial Policy Research Institute is proposing the "Life-cycle Impact Assessment Method Based on Endpoint Modeling" (LIME), which converts all environmental impacts to monetary terms and expresses them in numbers. At present, there may be no more convenient method to assess impacts, so under the circumstances it might be a practical option, but it is important to be aware of its limitations when applying it.

9.2.6 LCA: Good, But Not Perfect

Thanks to ISO's initiatives to promote standardization, great strides have been made relating to LCA for products in terms of data preparation and interpretation and other assessment procedures. If we look at LCAs impact on the behavior of industry players and consumers, however, one could say that the situation today is still not ideal. We must improve consistency in the conditions for comparative analysis, system boundaries or spatial and temporal extent of analysis, compatibility of background data, impact assessments and interpretation, and improved methodology is still underway.

Anyone who tries to conduct an LCA immediately must encounter the shortage of data. In many cases, data must be borrowed from elsewhere, which means that there is little guarantee of their reliability. Published corporate data in some cases consist of the results only, and the actual details may be guarded as secret or confidential. There is also confusion relating to environmental impacts and interpretation. If we look at only one aspect and ignore others, it is possible to come to different conclusions than if we looked at another aspect.

LCA can only be effective if we identify products with equivalent functions, and then focus the debate on the aspects that are different. When working with different functions, it is necessary to properly consider the properties of products, system boundaries, and data compatibility.

9.3 Renewable Energy and Energy Conservation

9.3.1 Japan and the United States: Options Differ

The discussion in Chap. 6 suggests that a major challenge for this century will be the creation of the low-carbon society. Let us consider the issue here from a perspective of energy.

Energy problems involve two dimensions: first, the development of alternative energy sources to replace fossil fuels, particularly oil; and second, the improvement of energy use efficiency. In his inauguration speech in January 2009, incoming United States' President Barack Obama declared, "We will harness the sun and the winds and the soil to fuel our cars and run our factories." But is this possible? The Bush Administration took a negative stance toward action on global warming, but the fact is that the United States possesses enormous potential for the development and use of renewal energy, including photovoltaic power generation in the vast desert areas of Arizona and Nevada, wind power generation in Texas and California, and biofuels from corn grown in the agricultural belt of the Midwest.

In his speech, President Obama declared that Americans will "build electric grids and digital lines," and "restore science to its rightful place," but made no mention of nuclear power, nuclear fusion, or space development. In terms of wind power, Germany is currently number one in the world with 21.8 million kW of capacity, followed by the United States, with 16.8 million kW. The total power generation capacity of Japanese electrical utilities is about 230 million kW, but of that, wind power generation provides only 1.67 million kW (1,409 windmills) (all figures as of end of 2007). Ideal sites for wind power generation are places that have consistently strong winds such as in Shimokita Peninsula, Aomor (Fig. 9.3), but the rotors make noise, so there are strict constraints on where wind turbines can be installed; thus, Japan does not offer much development potential for this type of energy.

Meanwhile, biofuel development potential is also limited in Japan, as the country imports 40% of its food, so whether we should use farmland for biofuel production is a question. The most promising options in Japan are the greater use of solar energy, and improvements in demand-side efficiency in energy use—in other words, energy conservation. Biomass could also be important as a means to utilize the forests,

Fig. 9.3 Wind power stations in Shimokita Peninsula, Aomori, Japan

which account for 68% of Japan's land area. President Obama's declaration that he would use renewable energy to fuel cars is perhaps a reflection of the American car-based society, and the mention of running factories may appeal to Americans' love of big things. Japanese aesthetics and special skills reside more with small and delicate things. The common expression *mottainai* (dissatisfaction about waste when something's intrinsic value is not properly utilized) is also an indication of traditional Japanese character. The potential for energy conservation in Japan depends on the Japanese inclination for these things. We certainly hope that President Obama's policies emphasizing the environment will succeed. But Japan, a country with only one twenty-fifth the land area of the United States, must take a different approach.

9.3.2 Solar Power: Large-Scale Centralized, or Small-Scale Decentralized?

The amount of solar energy entering the Earth's atmosphere at a perpendicular angle amounts to 1.37 kW/m^2; this figure is referred to as the solar constant. After entering the atmosphere, solar energy is absorbed and scattered by molecules of air. The solar energy that reaches the ground is the sum total of the amount that reaches the ground *directly* (direct insolation, which *can* be focused by a lens) and the amount that reaches the ground after being *scattered* in the atmosphere (diffuse insolation, which *cannot* be focused by a lens), and this is called the net surface solar irradiation.

Direct insolation in February in Matsumoto (on the Japanese island of central Honshu in Japan) amounts to 0.93 kW/m^2 (value for perpendicular rays). The Direct insolation might feel hotter during the hot summers, but if one were to measure the perpendicular rays, the value is higher in the winter, thanks to the clearer air. Net surface solar irradiation is affected by the latitude and weather conditions at each location, but the average for all of Japan is 0.14 kW/m^2. This is the value for a horizontal surface, and in fact is the average of all daytime and nighttime hours for the year, so it is only about one tenth of the solar constant. Today, the efficiency of photovoltaic power generation is about 20%, so to obtain 1 kW of electricity, about 35 m^2 of surface is required if that surface is horizontal. This value of total solar radiation on the right may seem small, but 1 km^2 of land receives 140,000 kW, which is not so small. A surface of 100 km^2 receives 14 million kW, so photovoltaic cells rated at 20% efficiency would produce 2.8 million kW, which is comparable with the output of a nuclear or thermal power plant.

The building of large-scale solar power plants (e.g., mega-solar power plants) using so much land area, however, is not always practical in Japan. Japan has a high population density and a small amount of open land, so one good option might be to use every available sun-facing wall and roof on homes and buildings to generate power. The problem, however, is that power generation and electricity use fluctuate with weather conditions and time of day or night.

Solar energy exists in great abundance, but there are still obstacles to using it effectively. To begin with, the upfront cost of equipment is high. Furthermore, as the supplied amount of energy with weather conditions, many technical issues remain when it comes to using solar together with power supplied by electrical utilities. In the past, the Japanese power system was built based on the need for efficiency by constructing large power plants, but in the future it will be necessary to also consider incorporating small-scale distributed systems. To turn all this into a stable system, Japan will have to invest in new energy infrastructure. If the problem of cost could be overcome, technological constraints would pose no serious obstacles, but the fate of solar power will likely be determined by the price of fossil fuels and the degree of urgency and action on global warming countermeasures, and, further, concerns about the risks of nuclear power plant accidents.

The use of solar energy has tremendous potential in developing countries that do not yet have large-scale centralized power distribution systems. This point can be appreciated if one considers how the use of wireless mobile phones has skyrocketed in developing countries, which were delayed in their installation of infrastructure of fixed-line telephone networks. It is exactly because extensive power distribution systems do not exist, conversely, that it is probably easy to build electrical power systems on a small, local basis. Meanwhile, in regions that are late embarking on the path of economic development, a simple device known as a solar cooker is an excellent solution. This is a device with a parabolic mirror about 1.2 m in diameter that focuses and collects solar heat for cooking. It is an interesting method.

9.3.3 The First and Second Laws of Thermodynamics

Energy has various uses, but one of the largest categories of energy demand in the residential and commercial sectors is for room heating and cooling, and for hot water supply. These requirements utilize energy in the form of heat, but in reality, it is wasteful to use high-quality sources of energy such as oil and electricity just for heating. Heat is a low-quality form of energy present all around us. Its effective use is the key to energy conservation in the residential and commercial sectors.

People often talk of "consuming" energy or "consuming" electricity, but these expressions actually contradict the first law of thermodynamics (or the law of energy conservation). Energy is always conserved; electricity consumed to do work is simply converted into heat. It is not possible, however, to convert all the energy that has been changed to heat back into energy to again do work. This is the second law of thermodynamics (or the entropy law).

Let us explain the second law of thermodynamics in basic terms. There is high-quality energy and low-quality energy, and when energy is used the *amount* of energy does not change, but its *quality* will always deteriorate. Low-quality energy is difficult to use even if one wishes to use it effectively, as it is in an inconvenient form. Oil and electricity represent high-quality forms of energy: they can easily be used to power automobiles and motors. Low-quality energy such as the heat in hot water, for example, cannot be easily used to move something. After oil or electricity has been used, the energy deteriorates into the low-quality energy that takes the form of heat.

9.3.4 Subdivided Energy: Difficult to Use

We have described heat as a low-quality form of energy, but let us consider what that means. The true identity of heat can be described as the kinetic energy of atoms and molecules that form an object. A ball thrown into the air will lose speed to wind resistance and eventually fall. The kinetic energy in the ball is lost to air friction, but a large portion of that becomes kinetic energy in air molecules, raising the air temperature by an imperceptible amount. We could say that some of the mechanical energy of the ball has been dissipated as heat.

One key to understanding the dissipation of energy is the difference between the macroscopic and microscopic degrees of freedom. The things we use in day-to-day life are macroscopic objects, such as balls and pencils, for example. The mechanical energy of macroscopic objects (kinetic energy and potential energy) is determined by their velocity and position. In contrast, the microscopic degree of freedom relates to the position and momentum of atoms and molecules that make up the object. The objects we handle day to day, no matter how small, are made up of atoms and molecules that number on the order of Avogadro's constant (6×10^{23}).

The true nature of heat is energy distributed with the microscopic degree of freedom of huge numbers such as this. It is as if energy has been separated into a countless number of pieces. If energy that was distributed with a macroscopic degree of freedom is distributed into a countless number of molecules, then it all becomes dissipated, making it impossible to completely recover: this is because the number of atoms and molecules making up the object is astronomically large (the number of degrees of microscopic freedom). In a way, the law of increasing entropy uses this astronomically large number to play a trick.

A person holding a thousand dollar bill can make a meaningful purchase, but if that same amount of money is distributed among 1,000 people, each person receiving only 1 dollar, no one will be able to purchase anything of great value. If 10,000 people receive only 10 cents per person, their options are even less. The total amount of money has not changed, but the buying power of the individual portions becomes almost useless. To make one large purchase someone would have to gather together the dispersed money, but that would not be easy to do. The dissipation of energy as heat is similar to this.

9.3.5 Exergy: Available Energy

Heat is present in the world around us in many forms, such as in the water left after a hot bath, for example, or flowing out of the heat exhaust of air-conditioning equipment. The quality of energy of this heat is not high, but the amount is large. Thus, one important challenge to improving environmental technology is to find ways to effectively use this heat. The concept of "exergy" is useful when considering these matters.

Generally speaking, the term *exergy* refers to the amount of energy that can be extracted from an object by exploiting differences in condition between the object and the external environment. The hotter an object, the more thermal energy it contains, but to extract that energy it is necessary to use a temperature difference with the surroundings (i.e., a low-temperature heat reservoir). If the temperature difference is zero, it is not possible to extract heat, regardless of how hot the object is. The exergy would be zero and it would not be possible to convert the heat into work. In other words, the amount of energy that can be effectively extracted from an object is determined by the temperature of that object and the temperature difference between it and the surrounding environment. Thus, the amount of exergy is determined by the relationship of an object with its surrounding environment.

For instance, the amount of exergy of water at 50°C is different when the surrounding air is 0°C compared to when the air is 30°C. When the outside air temperature is 30°C, the temperature difference is 20°C, but when the outside temperature is 0°C, the temperature difference is 50°C. It is therefore in the latter case that the energy that can be effectively extracted from the water—the exergy—is larger. This example focuses on the temperature difference between an object and its surrounding environment. Conditions in which the surrounding environment has higher pressure, or higher concentration, also have exergy. Moreover, when the surrounding environment has a lower temperature, lower pressure, or lower concentration, these are conditions in which energy can be extracted by using the difference in conditions between the object and the surrounding environment, so they also contain exergy.

Many things in the world around us contain unutilized exergy. For example, the wastewater discharged from households into the sewerage system has a higher temperature than the local river water. Snow that has fallen during the winter, if piled up and stored under cover until summer, will have a temperature lower than its surroundings. In each case, exergy exists because of the difference in temperature. Exergy is also present in the different salt concentrations where freshwater and saltwater mix.

Energy, entropy, and exergy—all these terms come from Greek origins. *En* is a prefix that means "in" or "within." If we attach *ergon*, which means "function, task, or work," we have *energy* (latent power to do work); if we attach *tropy*, which means change or transform, we have *entropy* (qualitative changes caused within something or internalize change). Finally, if we add the prefix *ex*, meaning "outside" or "external," to *ergon*, we get *exergy*. In other words, exergy is energy that can be drawn out of something.

9.3.6 Efficient Use of Energy Using Heat Pumps

The heat in the hot water after a bath cannot easily be used to operate a machine, but it can be put into a hot water bottle to keep a person warm. The best way to use the low-quality energy effectively is to use heat as heat. Heat pump technology is for exactly this purpose, and it is employed widely in household air-conditioning and refrigeration equipment. Air conditioners and similar equipment contain a type of substance used as a refrigerant. Examples include chlorofluorocarbon (CFC) gases—which became a problem because of their destructive impact on the Earth's ozone layer—and their alternatives (CFC alternatives). When changing state from liquid to gas (vaporizing), refrigerants take heat from their surroundings, and conversely, when they change state from gas to liquid (condensing) they release heat to the surroundings. One property of gases is that their temperature drops from adiabatic expansion, and on the other hand temperature rises from adiabatic compression.

When a compressor forces a refrigerant to alternately expand and compress, the refrigerant's temperature falls and rises. If a refrigerant in a cool, condensed state is put into an object warmer than the refrigerant, the refrigerant will take heat from the object. Conversely, if a refrigerant in a warmer, vaporized state is put into contact with an object cooler than the refrigerant it will transfer heat to the object and be condensed. By repeating this cycle, it is possible to take heat from a low-temperature object and transfer it to a high-temperature object. From the perspective of a cool object, this is cooling, but from the perspective of a hot object, this is heating.

The amount of heat that can be transferred by a heat pump is several times larger than the work energy required to operate the compressor. This statement may appear to violate the law of conservation of energy, but actually it is only transferring heat as heat. The main point is that the energy is not being converted into work. To do work with a steam engine, for example, high-temperature steam is needed, and for this it is necessary to burn coal to heat water. In contrast, the thermal energy required to heat or cool a building is needed only to maintain the room temperature. Calculated in terms of exergy, the amount of thermal energy required is small—an amount that a heat pump can easily draw from the surrounding environment.

Thus heat pumps are efficient, because they do not heat the air directly, in contrast to electrical or oil heaters. To understand how a heat pump works, let us consider the concept of "Carnot efficiency" for a moment. Nicolas Léonard Sadi Carnot was a French scientists who, in the late eighteenth and early nineteenth centuries, studied the question of the maximum amount of mechanical work that can be extracted using the temperature difference between two objects, one a high-temperature heat source (absolute temperature, T_1), and one a low-temperature heat source (absolute temperature, T_0). He reached the conclusion that the maximum amount of work E that can be extracted from the thermal quantity Q transferred from a high-temperature heat source to a low-temperature heat source could be calculated by the following equation, where η is the Carnot efficiency.

$$E = \eta Q$$
$$\eta = \frac{T_1 - T_0}{T_1}$$

The principle of the heat pump makes use of the reverse of the Carnot cycle. That is, instead of extracting work E by transferring heat Q from a high-temperature source to a low-temperature heat source, by having an external source do the work E (i.e., for moving a compressor), the heat Q is transferred from the low-temperature heat source T_0 to the high-temperature heat source T_1. The amount of heat transferred Q divided by the electricity consumed E produces the coefficient of performance (COP), whose theoretical limit is the inverse of the Carnot efficiency ($1/\eta$). Figure 9.4 illustrates the principle of the heat pump.

In Japan, a government-sponsored award program called the "Top Runner" program was launched to recognize products, such as automobiles and household appliances, that have the best energy efficiency in their category, and it is helping to dramatically improve the efficiency of air conditioners and refrigerators in this country. The COP value of air conditioners has increased from about 3.0 in 1990 to 6.0 today (2009) as a result. Even in cold places such as Hokkaido in northern Japan, the temperature below ground is almost constant year-round; in winter it is considerably warmer than the air temperature outdoors. In such a region, it is possible to draw heat from the ground using a heat pump and use it to heat a room.

9.3.7 Biomass Energy

In the past, the main fuels used in Japan were firewood and charcoal. The amount of carbon stored in trees growing in Japanese forests varies depending on the tree species, but is generally about 60–100 tons/ha. Assuming an average of 80 tons/ha, and assuming that about 70% of Japan's land area is covered by forests, the total would be about 2 billion tons. This is a rough indication of the amount of carbon sequestered (not counting the amount contained in forest soil) in forests in all of Japan. Incidentally, Japan's carbon dioxide emissions amount to about 370 million tons (in terms of carbon equivalent) per year. If we assume an average tree age of 30 years, the annual amount of carbon fixation is about 70 million tons, but this is only if the amount of logging is in balance with the amount of tree planting, so the net increase or decrease would be zero.

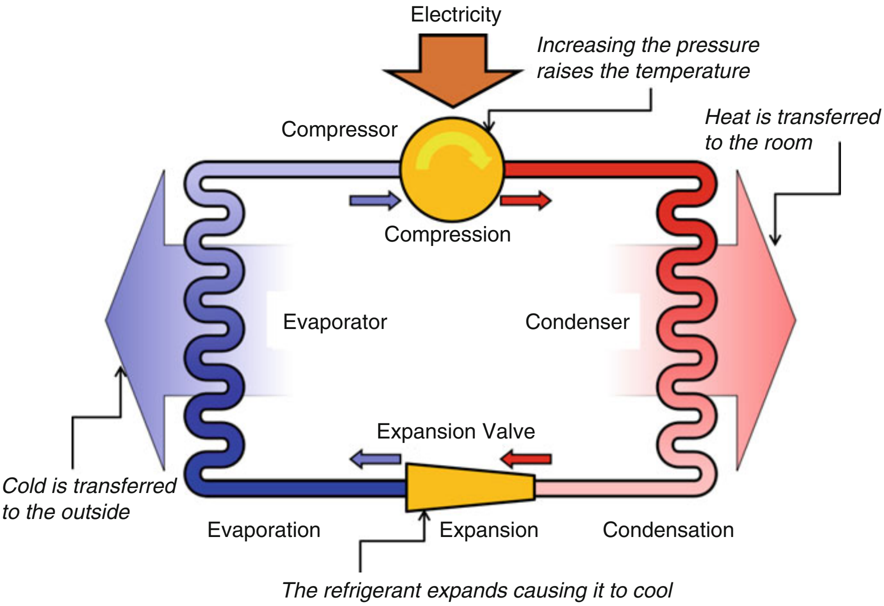

Fig. 9.4 Principle of a heat pump (heating in this case)

The Japanese government's Kyoto Protocol Target Achievement Plan declares the intent to use tree planting to achieve a 3.8% reduction (13 million tons) as part of the national 6% emissions reduction target from 1990 levels, but this has to come from planting of new trees, so this plan will not be so easy to achieve. As the previous numbers indicate, even if Japan managed all of forests properly, the usable amount of timber would be a maximum of about 70 million tons (carbon equivalent). In reality, forest management in the mountains is difficult work, and after subtracting the amount of energy used for logging operations, plus transporting and processing the timber, the net amount of usable biomass from forests is not as large as one would hope, although there is good potential for using it in local cities closer to the forests.

In addition to wood and charcoal, other forms of biomass include food waste (kitchen waste, food leftovers, unused food, etc.), sewage sludge, and animal waste. These wastes can be fermented to produce methane, which can be mixed with municipal natural gas and then used. Until the 1970s, many households in India used simple systems to produce methane from human waste for use as a cooking fuel, but such systems have almost completely disappeared.

Modern cities have installed technology systems such as large-scale sewage systems, garbage incineration plants, and electricity and gas supply systems, making it difficult to use decentralized resources and energy at the level of the individual or household. The human waste collected at the sewage plant could be used as a raw material to produce methane, but because it is not profitable at present, little progress is being made with this use of the sewage sludge. Methods also exist to produce methane from kitchen waste in urban garbage without incinerating it, but in Japan, municipal waste is incinerated for sanitary reasons.

One of the problems with the technology systems that sustain modern society is that once they have been installed, they cannot be easily changed. Even if a new system is superior, change is still difficult, because modifications of the installed system will result in some waste of previously invested funds. In this sense, it is worth noting that developing countries may have more flexibility than developed countries when it comes to introducing new technology systems because of their later development.

9.4 Environmental Choices: Not Simple

9.4.1 Criteria for Comparative Assessments

Debate often rages about which products and technology systems are better for the environment, or what are their most desirable characteristics. Actually, this question may not be so easy to answer. To begin with, when making a comparison, one challenge is sorting out the conditions or criteria. An automobile and a television have different functions, so it is difficult to compare the two. When making comparisons it is essential to discriminate the functions, and it is important to carefully consider to what extent that is even possible.

Next comes the issue of the reliability of the data being used. It is not always possible to obtain reliable data about the various aspects of a product or technology system. Without the cooperation of companies it is difficult to obtain reliable figures on the amount of resource inputs or environmental impacts per unit of production of a product or material. Even if data have been provided, it is often extremely difficult for an outsider to verify their reliability, so collaboration for data collection and improvement and information disclosure from industry are essential.

The biggest problem is that there is no consensus yet on how to interpret the data on the use of resources or the generation of environmental impacts. In the case of LCA, even if the inventory analysis has been done properly, the next problem is how to do the impact assessment. In many cases, depending on the assessed categories, the results of the assessment will differ. It might be possible to impose some kind of weighting system on the assessment categories, based on public opinion surveys, for example, to standardize the assessment items, as done in LCA, but there are many divergent opinions on this. There is also the problem of deciding how far to go in considering the spatial or time scales of the impacts.

Furthermore, people do not choose products or technology systems just based on the environmental dimension alone, so it is necessary to conduct integrated analyses together with other factors, such as convenience and economic efficiency.

9.4.2 Top-Down Management for Macro-level Objectives, Informed Choice for Micro-level Behavior

In day-to-day life, many people have probably experienced times when they were frugal on the little things, but wasteful on the big things. When buying little things we may pay attention to a difference of even 1 yen, but when shopping for large items we might be less careful about price. Similar things occur when selecting products. It is certainly a good thing to pay attention to the environmental friendliness of each separate product. Economic systems, however, consist of countless intricately interrelated factors. Something that we thought may have been good on one dimension, may, through a variety of linkages, have unforeseen negative impacts.

Modern economic theory on consumption and production asserts that the self-interested actions of consumers and producers will result in the optimum and most efficient resource allocation. Consumers with limited budgets make choices about the goods they purchase in such a way as to maximize their utility. One person, instead of spending money on food, might prefer to save money for clothing, and another person might make the opposite choice. That freedom of choice is up to the individual, but because they have budget constraints, it is not possible to purchase more than their finite funds permit. When making choices on the purchase of each time, consumers choose the things that they believe will make them happiest, based on the limited information in their possession, even if they sometimes feel it is difficult to decide. It is not assumed that all individuals will behave in the same way; in fact, that diversity of individuals' behavior is one of the excellent aspects of the market economy. Ultimately, consumer behavior also has an impact on the behavior of the producers that supply the products, so if proper competition exists among producers, each will establish the product development strategy they believe to be best.

It is worth noting that the essential element for the market to function efficiently is correct information. The behavior of individuals who have better information will gradually have an effect on producers and on other consumers. For the benefit of the environment, it is desirable that consumers purchase products that are environmentally friendly, but it is difficult to forcibly control consumer behavior, and moreover, it is not practical to attempt to do so. The important thing is to provide information that consumers can rely on, and then leave the decisions up to their rational choice.

These days, the quality and quantity of information held by consumers relating to the environment is rising dramatically, and producers are also paying attention to the environment as a factor that can enhance product appeal. It is important to maintain momentum in this direction. At the same time, society as a whole must set carbon dioxide emission reduction targets, by country and by region, establish macro-level management targets for things such as resource productivity, and mobilize everyone to find ways to achieve those targets.

9.4.3 The Role of Government in Choosing Technology Systems

The foregoing discussion applies to cases in which consumers have the freedom to make the choice, but when it comes to the selection of technology systems for society, it is governmental policies and decisions that play the most important role. For example, in designing cities that will have low energy consumption, the urban planning normally decided by municipal governments is extremely important in terms of land use, public transport, building design, solid waste management and construction and maintenance of public infrastructures [7].

Policy decisions by governments, particularly for public works projects, should consider the environment, keeping many issues in mind as already stated. Governments must conduct a careful examination of the details of alternatives, data quality and availability, and choice of environmental indicators and interpretation. Depending on which criteria are given the greatest priority, assessments could lead to completely different conclusions. Ultimately, in many cases the decision is made based on analysis using currently available information, and in the face of considerable opposition. In some cases it eventually turns out that the final decision was not the best choice, and at that point it is sometimes not possible to modify the choice.

9.4.4 Waste: Incinerate or Recycle?

Another topic of debate on waste management today is whether to recycle waste or incinerate it. This is another area that has no agreed universal standards for evaluation, so it is possible to come to the opposite conclusion depending on which aspect is considered. Many different opinions have been expressed on these topics. For example, some say it is economically more rational to incinerate garbage and use the generated electricity or heat, because the necessary labor and high costs mean only a small amount of salvageable goods can be recycled, especially if materials separation and collection are done by hand. Others say that resources should be recycled and not incinerated at any cost. Still others say that precious resources should be recovered as a hedge against future resource shortages, and that research and development should be encouraged for this purpose.

The Japanese government has decided on a policy with the following prioritization for the handling of waste: re-use, reduce, and then recycle, and then the final option of "thermal recycling" (in other words, incineration). The first three items are the famous "3Rs" (or three Rs). In natural ecosystems all materials are recycled as material, and "thermal recycling" does not exist (although fires do occur from time to time). On this point, there is a difference between material circulation in the natural world and the technology systems of modern industrial societies. In fact, the Japanese government made thermal recycling the last choice after the 3Rs because of a desire to have artificial material circulation be as close to that of the natural world as possible. Indeed, this philosophy is very strong in Germany, which could be considered the world leader for policies relating to sound materials circulation.

Another reason for the necessity of thermal recycling is that humans are creating toxic substances that will not decompose easily in nature. PCBs are one such example. One ground to discourage thermal recycling is to create a disincentive for creating these types of toxic substances in the future. The petroleum-based plastics so popular today do not decompose easily in the environment either, and even if recycled, do not produce products of any particular value. It is hoped that starch-based biodegradable plastics will become more popular in the future.

The 3Rs and thermal recycling can be compared from the perspective of various considerations, such as cost, energy consumption, carbon dioxide emissions, and other factors. In some cases it may be that with current technologies and costs, the 3Rs may not be the best choice. In those cases, we need to remember that the conclusion is based upon currently available technologies and cost structures. Options that may seem unfavorable under present day economic and technological conditions may actually be rational choices in the future, if seen from the perspective of proactive future economic and technological changes.

9.4.5 Using Environmental Information to Make the Right Choices

Considering Japan's land and climate characteristics, solar power is the most promising renewable energy, but to promote its use, Japan must modify existing systems to make centralized systems and distributed systems work complementarily. For industry as a whole to conserve energy, in many cases each industry or corporation must make its own efforts. In the residential and commercial sectors, technological improvements for energy conservation—particularly for heat demand are likely to be effective in the following areas: high-efficiency insulation in buildings, air-tight building designs, and heat pumps.

Regarding the environmental impacts of products and technology systems, it is now possible to produce relatively reliable inventory analyses for each environmental category. The problems, however, are with interpretation of the findings. An efficient way to achieve environmental objectives is to set macro-level environmental management targets on the level of the state, municipality, community, and citizen group—relating to national carbon dioxide emissions, resource productivity, and waste recycling, etc—and at the same time, to allow freedom of choice for the micro-level behavior of corporations and consumers. To make all this happen, the role of accurate and relevant environmental information is very important.

The 3Rs (reduce, reuse, and recycle) may sometimes seem to be impractical choices in the short term, but it is important to think in the long term, with a view to technological developments that will make them more viable in the future.

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Chapter 10
Japan and an Asian Perspective

10.1 Asia in Transformation

When thinking about present and possible future environmental problems in Asia, it is clearly worth examining and learning—from both the positive and negative perspectives—from Japan's history of environmental issues that arose in the process of this country's industrialization [1, 2]. Although countries in Asia include both early and late starters on the path of industrialization, they tend to follow a similar pattern of development, even if the delay is a few decades—and the time lags are rapidly shrinking.

The recent history of economic development is brief in Asian countries, and the fruits of prosperity are not yet being distributed equitably within some countries. Thus, the income gap is tending to grow between urban and rural populations and between regions that develop early and those which develop later. While city dwellers are enjoying high-consumption lifestyles, many poor rural villages still do not even have electricity or running water. In many cases, the force of the waves of development in poor regions destroys not only the local environment but also traditional culture and the very basis of livelihoods in local communities. This situation causes problems for the management of local forests and other commons that have long been sustained, until now, by the local communities.

Some of Asia's problems can be resolved by economic progress, but that type of progress also causes new problems. Some of these, for example, will be industrial pollution stemming from the production activities of corporations, while other difficulties will relate to urban sanitation and drinking water issues. The drivers and causes of these problems are already known, and the menu of response technologies is also readily available. If a certain percentage of the funds that corporations and governments obtain through economic progress was made available for steady investment to improve the environment, then constant improvements would be possible. If this is not being done, then it is a sign of serious problems with the ability of governments to effectively do their job.

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Developing countries should be aware, however, that developed countries have experienced not only successes but also many failures; if they follow exactly the same paths as developed countries, they will inevitably repeat the same mistakes. Thus, Asian countries have some advantages in starting to industrialize later: by studying the experiences of developed countries, it should be possible today to plot the most efficient path to progress.

10.2 Asia and Globalization

The concept of "globalization" is an agglomeration of the values of contemporary Western society—faith in the market economy, liberalization of trade, capital, and investment, democracy, scientific rationalism; industrial modes of production, and so on.

Many Japanese would probably agree that all these ideas mean acting in accordance with a Western style of economic system and sense of values. Moreover, fully accepting these things has meant reluctantly relinquishing parts of their own culture and values. But some people wonder if these types of economic development, production, consumption, and lifestyles—originating under the leadership of the Western countries and currently spreading around the world—are good for the global environment. Today's global economic issues are making us ask new questions and strive to rethink these problems.

Some suggest that the key to considering a path of sustainable development in harmony with the environment this century is to reexamine traditional Eastern cultures and values in relationship—or in contrast—to those of the West. If globalization is going to further promote Western-style (particularly, American) systems of production and consumption, as well as the values upon which they are based, then this can only mean the destruction of social and cultural structures in Asia that have long been embodied in local traditional lifestyles, customs, practices, and values.

Economic globalization and the spread of market-based economies are destroying traditional rural village societies and local communities in Asia, as societies shift from an emphasis on strong local and family connections to becoming more individualistic. It will be important for Asia, buffeted in the middle of this huge and seemingly unstoppable tide of globalization, to learn from the noteworthy precedents established in the United States and European countries, and then to develop approaches that apply better to our own conditions. On this point as well, a good question to ask is this: What and how can Asia contribute? Here, at the same time, we must consider that Asia consists of a number of countries with different cultures, religions, political systems, and natural conditions, and we must be aware of their diversities and the difficulties in reaching a consensus about the directions and goals of their development.

10.3 Common Concerns, Cooperation, and the Future

The author wrote the first draft of this book early in 2009, with the world in the midst of an unprecedented economic crisis, making it difficult to easily forecast the future of both Asia and the rest of the world. Nevertheless, as a general trend, along with its rising industrial production, in this century Asia will probably account for a larger part of the global economy than it has in the past. At the same time, with its huge use of resources for industrial production, plus consumption by the large Asian populace (Asia has 50% of the world's population, and East Asia alone has 30% of the global total), this region may end up having the greatest impact on the global environment.

Nations such as China, India, and the members of the Association of South-East Asian Nations (ASEAN) have been able to achieve remarkable economic growth since the early 1990s, thanks in part to investment from overseas. Along with economic growth came new problems such as industrial pollution, water shortage, poor sanitation and resource constraints, but progress has been made in handling these needs. However, no country will ever be completely free of such problems.

It is clear that we cannot talk about East Asia without also talking about China, whether it concerns land area, population, projections of future economic size, or other topics. It is worth noting that of total global carbon dioxide emissions in 1990 from fossil fuel consumption, the United States accounted for 23.3% and China for 11.1%, whereas in 2009, the United States was at 18% and China had grown to 24%. China's carbon dioxide emissions first surpassed those of the United States in 2007, and it is predicted that Chinese emissions will continue to increase. Furthermore, ASEAN is an important player, as the combined population of member countries is larger than the populations of either the European Union or the United States. The future of the environment in East Asia will probably be largely determined by tripartite relations within the region among China, ASEAN countries, and Japan, plus the influence of the United States across the Pacific Ocean. Likewise, we must pay special attention to India when we talk about South Asia.

There is also no doubt that competition for the growing Asian market will intensify between Western countries and Japan. This will also likely be the case with the transfer of environmental technologies. Although Japan has been proud of its advanced environmental technologies, it cannot claim to have a monopoly on them. Also, all need to recognize that what Asian countries need are low-cost technologies that are easy to maintain and operate. It is also worth noting that China and other countries are beginning to show promise in their own development of technologies in this field.

Environmental problems in the twenty-first century are shared problems that Asian countries must face together. It is important to recognize the importance of the role of environmental technology transfers and funding grants that promote specific areas. The Clean Development Mechanism (CDM), used as a measure to counter global warming, is one example of new joint efforts beginning between developed and developing countries.

From a larger perspective, we will realize that the region has enormous growth potential. As we move forward, it will be extremely important to seek harmony between the environment and the economy. Thus, a key challenge will be the further development of environmental studies that can contribute to efforts to contend with both environmental and economic problems in this region.

10.4 Japan After the Great Disaster

10.4.1 Triple Disasters

The aim of this book was to explore environmental problems together with readers, and we touched upon environmental policy issues in Japan from place to place, but Japan today is facing even tougher problems than before.

The disaster that occurred in eastern Japan in March 2011 involved an earthquake, tsunami, and an accident at a nuclear power plant, causing tremendous damage in a wide area along the coast. In all, 16,000 persons lost their lives, and many homes, buildings, and workplaces were also lost. The economic and social impacts were profound. The Tokyo Electric Power Company (TEPCO) that caused the nuclear accident in Fukushima supplies electricity to the Kanto region, which is central to the Japanese economy, and covers the metropolitan area around Tokyo having 42 million people. Immediately after the disaster, the entire Kanto region was plunged into a severe power shortage. Factories and offices had no choice but to restrict their business activities. Households in some areas also had to endure scheduled power outages to save electricity.

The disaster had interrelated, profound, and complex impacts on Japan in three dimensions: economic, energy, and environment. The question of how to secure a stable supply of electricity, and the question of what should be the future mix of electricity sources, these are critical issues for the nation's economic and energy policies, but they now also have an enormous bearing on environmental policy.

Japan hosted the Third Conference of the Parties to the United Nations Framework Convention on Climate Change in 1997, and since then has been making an effort to achieve the targets agreed upon in the Kyoto Protocol. The country has studiously prepared and implemented measures to achieve the national emission reduction targets for greenhouse gases, as agreed under the Kyoto Protocol. It was also developing a plan to achieve the medium-term national target of a 25% reduction in total greenhouse gas (GHG) emissions by the year 2020, and was preparing a road map to that end. That scenario, however, was premised upon greater dependency on nuclear power as indicated by the national energy supply and demand forecast. Currently, many nuclear power plants in Japan are not operating. If this situation continues, the assumptions underpinning the future GHG emissions reduction scenario may collapse.

10.4.2 Economy Versus Environment Again

A country with almost no fossil fuel resources of its own, Japan has placed an emphasis on securing stable sources of energy, and on the stable supply of electricity. Japan's overseas payments for the import of fossil fuels has been on a rising trend, and in 2010 exceeded 20 trillion yen, this amounted to 4.5% of the nation's gross domestic product. Many are concerned about the large burden on the Japanese economy of rising energy prices caused by the increase in international fuel prices, and nuclear power was seen as a quasi-domestic source of energy. Thus, the nation's long-term plans for energy supply and demand have assumed that there would be a stable use of nuclear power. A stable supply of electricity is a life-and-death matter for industry, which explains the industry's support for the use of nuclear power. The public, too, accepted the myth of the safety of nuclear power, even while harboring some concern about accidents at nuclear plants.

Today, after the accident, Japanese public opinion is dramatically split on the topic of nuclear safety, and some are strongly calling for the complete abolition of nuclear power. In the midst of huge uncertainties arising about power supply capacity, hopes for initiatives to move toward a low-carbon society are pinned on large increases in the efficiency of energy use, and these are also compatible with the move toward nonnuclear energy. This approach is compatible with the direction of policies such as green innovation, which aims to realize a virtuous cycle between environment and economy, the green economy, and green growth. Technologies that are crucial for the creation of a low-carbon society include those such as renewable energy, notably photovoltaic power generation, as well as smart houses and smart grids, which use advanced information and communication technologies.

Before the disasters, there was little serious debate about nuclear issues in Japan in the context of creating a low-carbon society. After the disasters, public debate began to cover a broad range of perspectives including nuclear issues. However, there is a large divergence of opinion, depending on the region and on the person. Clearly the greatest common factor to resolve all issues is that it is desirable to shift toward lifestyles, business styles, housing, buildings, electrical equipment and devices, and transportation systems that consume the least possible amount of energy.

10.4.3 Inter-regional Equity Concerning Nuclear Power Plants

There is a disparity in the perception of risks of nuclear power between the residents living near nuclear power plants, who have a heightened level of safety concern, and the residents of large cities located at some distance from the plants. For reasons of local economic and employment benefits, some residents living near nuclear plants support the operation of nuclear power on the assumption that this is safe and beneficial for the local economy.

There are similarities among the nuclear power plant sites in Japan. All of them are near the coast, and all are in sparsely populated areas. Nuclear plants are a source of anxiety for communities where they are located. To ease this anxiety to certain extent, large sums have been paid in subsidies to municipalities that accept nuclear plants, and to their neighboring towns, and those funds have helped to vitalize the local economies to a certain extent. The reality is also that nuclear-related work creates employment. Local agreement is required to build a nuclear plant, but this is seen as an important matter of national economic and energy security, and the ultimate decision-making authority rests with the national government. As a result, the situation is that consent has been bought by money, under the strong will of the national government and power utilities seeking to build nuclear power plants.

Pronounced differences in the perception of nuclear power have appeared between the central government and the regional communities hosting the power plants, and also between the people in those host regions that supply the electricity and the people who mostly live in large cities where the electricity is consumed. Before this situation can change, there is a need to discuss the equity issues among different regions and different people and to redefine the purpose, necessity, and significance of creating the low-carbon society..

10.4.4 Centralized Versus Decentralized Approach

Until now, initiatives about low-carbon cities were based upon the major premise of a comprehensive national energy strategy decided by the central government, supported by industry, and an electrical supply system premised upon nuclear dependence. Japan's electricity supply system is operated by nine power utilities that enjoy regional monopolies. Problems with the conventional electricity supply system designed with the highest priority on stability of supply were often pointed out in the past, but in the face of the enormous influence of both government and power utilities, questions and criticisms were drowned out.

The power utilities have been unenthusiastic about the Renewable Portfolio Standard (RPS) system, by which power utilities are required to purchase renewable energy such as solar, wind, and geothermal power. Although the system has been in effect since 2003, the purchase prices have been kept low based on the power utilities' assertion that the supply capacity is variable and unstable. The disaster, however, has created the opportunity to reexamine these longstanding issues. A shift is being considered from this RPS system, to be replaced by a "feed-in tariff" system, under which power utilities are expected to purchase electricity at a price fixed by the government. Higher purchase prices will provide a larger incentive to develop renewable energy power. The deployment of renewables, however, takes time, and its short-term capacity is limited.

For the creation of low-carbon cities, before the Great East Japan Earthquake, it was assumed that the power mix and price of electricity were matters for the national governments and power utilities to decide, and municipal governments had no room to make adjustments. Since the disaster, an idea gaining momentum is that to be prepared for emergencies, cities should not rely entirely on electricity from the power utilities' grid, but should also use the maximum amount of energy available from within the city, The challenge is how to create low-carbon cities, while also paying attention to economic, energy, and environmental security at the local level:

In response to the increasing demand for GHG emission reductions under national and local government policies, private companies are developing new technologies and business models that could serve as a starting point for an alternative energy infrastructure. The calculations of return-on-investment from nuclear power do not properly include the costs incurred for the treatment of nuclear waste and the huge cost of damage compensation once an accident takes place. If the true costs and security risks of nuclear power technology were correctly accounted for, solar power would be relatively less costly. The generation and provision of electricity from renewable energy sources requires the dissemination and use of certification systems such as green energy certificates. New technologies for electricity storage by using batteries of Electric Vehicles (EVs) may bring about drastic change in energy supply systems in the future. Information technology is also becoming the center of interest as a basis for controlling energy demand and allowing the reduction of supply, as well as for increased efficiency in the transport sector.

As the majority of energy used in households is for heating water, there is an idea that it would be more cost effective to invest in solar water heaters instead of the costly photovoltaic panels. The target of subsidies, whether it be photovoltaic panels, solar water heaters, or co-generation technologies, will be considered based on their extent of distribution and citizens' demands. There are institutional barriers to the introduction of new energy management solutions. Smart grids and renewable energy are assumed to come in tandem, but in reality, peak cuts through the use of electricity storage technologies would suffice to overcome energy shortages in Japan without using renewables. However, there is a regulatory barrier to the development and distribution of new technologies such as electricity storage devices using EV. Regulatory reforms should thus be the center of debate to address not only energy issues effectively but also promote low-carbon cities and eco-cities [3].

10.5 Environmental Policy Facing Social Transition

Japanese society is aging at a rapid pace, and it is projected that in 2050, 40% of the overall population will consist of seniors 65 years of age and older. The challenge for the country is to maintain the dynamism of society while also creating cities and regions where seniors can live safe and healthy lives.

Since the Great East Japan Earthquake, Japanese energy and environmental policy has been in disarray. Even before the damage caused by the disaster, urban planning concepts in Japan have been in the midst of dramatic change, in response to a declining population, fewer children, and an aging society. The situation in the areas affected by the disaster is like a mirror reflecting the current situation in regions of Japan outside the large cities. Years before it started to happen in large cities, those areas already had fewer children and more elderly. There, it is essential to promote integrated policies for the local economy, employment, health, and welfare.

In a sense, Japanese society is approaching a mature phase today. The Japanese economy is starting to lose the dynamism and vigor that it had during its period of rapid economic growth, and people are generally satisfied with the quality of their air, water and natural environment—which are visibly cleaner and greener than they were 20 or 30 years ago—and are enjoying lifestyles of material sufficiency. People are demanding safety and security today rather than conspicuous affluence. The public is aware that the choice is not between environment and economy, but that it is possible for both to have a favorable impact on each other, in a positive cycle.

With the reality of a disaster so dramatically evident today, the importance of local communities and the importance of people-to-people solidarity and mutual support has been reconfirmed. These observations can give us hints about the role of community in creating a low-carbon society.

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