# Chapter 10
# Concept of the Environment and Environmental Systems

**Hirofumi Nakayama**

**Abstract** In this chapter, we explain the basic concepts of the environment and environmental systems analysis. In Sect. 10.1, the concepts of environmental problems are explained using the environmental capacity relationship between the nature and scale of human activities. In Sect. 10.2, the basic concepts necessary for environmental protection are explained. Finally, in Sect. 10.3, the procedures and methods of environmental systems analysis are detailed in a systematic analysis of environmental problems focusing on the relationship between the natural environment and human activities.

**Keywords** Environmental capacity • Eco-efficiency • Basic concepts of environmental protection • Environmental systems analysis • Causal relationship diagram • Model analysis • Scenario analysis

## 10.1 Environmental Capacity of the Nature and Scale of Human Activities

The socioeconomic system developed thus far has extracted a large amount of natural resources, used these resources as raw materials to mass-produce intermediate and final products, and consumed and disposed of these products. In other words, it has been criticized as a system standing on mass production, mass consumption, and mass disposal. We enjoy convenient and rich lives by consuming a large amount of resources with excessive resource extraction, pollutant emissions generated during production, and unnecessary waste created in the consumption stage. These activities burden the natural environment, preventing material circulation in nature (Fig. 10.1).

The natural environment has the power to regenerate and restore itself even if it undergoes external changes. The regenerative and self-restorative capacity of nature is called environmental capacity. In the field of ecology, environmental capacity has

H. Nakayama (✉)
Department of Urban and Environmental Engineering, Kyushu University, Fukuoka, Japan
e-mail: nakayama@doc.kyushu-u.ac.jp



T. Shimaoka et al. (eds.), *Basic Studies in Environmental Knowledge, Technology, Evaluation, and Strategy*, DOI 10.1007/978-4-431-55819-4_10

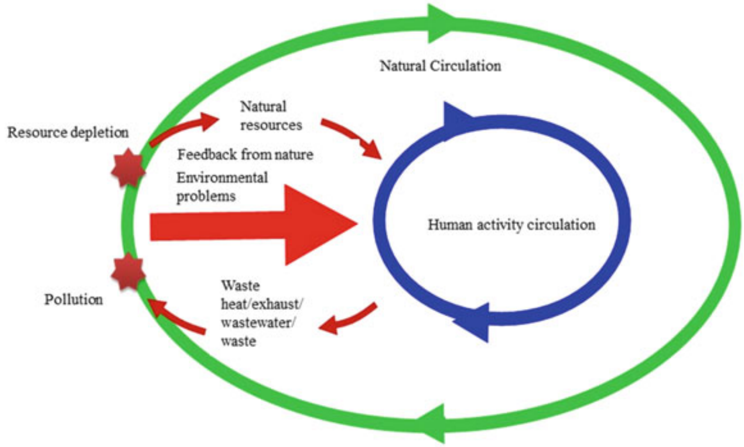


**Fig. 10.1** Material circulations in nature, human activities, and environmental problems

been studied as the capacity of the natural environment for biomass and diversity. However, environmental capacity is limited. If a change occurs that surpasses the environmental capacity, the environment is damaged. Currently, mass extraction of resources from the natural environment and environmental burden of pollutants and waste from human activities are threatening human being survival. Therefore, resource consumption and pollutant emission from human activities must remain within nature's environmental capacity range. In addition, some technology measures to increase nature's environmental capacity have been considered.

Economist Herman E. Daly focused on transportation of materials between the natural environment and human society, for example, resource use and pollutant emission. He proposed the following three principles on sustainable rates (Herman 1990):

For a renewable resource—soil, water, forest, and fish—the sustainable rate of use can be no greater than the rate of regeneration.

For a nonrenewable resource—fossil fuel, high-grade mineral ore, and fossil groundwater—the sustainable rate of use can be no greater than the rate at which a renewable resource, used sustainably, can be substituted for it.

For a pollutant the sustainable rate of emission can be no greater than the rate at which the pollutant can be recycled, absorbed, or rendered harmless by the environment.

One method used to determine (1) the sustainable utilization rate of renewable resources is the maximum sustainable yield (MSY). It refers to the maximum sustainable harvest that does not reduce the level of resource stocks. The harvest of renewable biological resources (e.g., fish) must remain within the range of the net reproduction rate (i.e., the number of resource units increasing per hour) generated from a certain amount of resource stock. The maximum production possible while maintaining the stock is MSY (Ueta 1996).

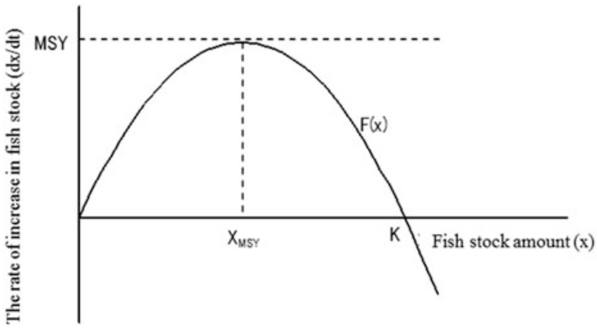


**Fig. 10.2** A natural growth model of fish (*Source*: Ueta 1996)

Figure 10.2 shows a natural growth model of fish as a relationship between the rate of increase in the stock of fish and the existing stock amount. Considering a case where fish enters a new habitat with plenty of food, the rate of stock increase is significant. As the stock increases, the marginal rate of increase drops. When the stock amount reaches the environmental capacity K, the marginal rate of increase is 0. Then, the rate of increase peaks when the stock is one-half the environmental capacity K. If this level of stock is maintained and only the marginal quantity of fish is harvested, the maximum harvest can be maintained without exceeding the resource regenerative capacity.

This idea is utilized as the basic concept of using renewable resources in fishing, hunting, forestry, and agricultural production.

Next, for (2) the sustainable utilization rate of nonrenewable resources, we discuss the sustainable use of fossil fuels, such as oil. With a system that invests a portion of the profits from using oil in the development and promotion of technology for using alternative resources, alternative renewable energy can be continuously used even after the recoverable reserve is mined to exhaustion and the nonrenewable resource is depleted.

The use of renewable and nonrenewable resources must consider the resource regeneration rate and the rate of technology development for alternative resources. For the present and future population to enjoy a healthy and rich environment, this environment must be properly protected. The current generation cannot use an unlimited amount of resources to allow future generations to inherit these resources. Thus, fairness between generations—securing environmental resources for future generations—must be examined.

Finally, for (3) the sustainable emission rate of pollutants, there is a method of establishing environmental standards (that should be maintained to protect human health and secure the living environment) based on the relationship between this rate and environmental capacity. In other words, in this approach, environmental standards are set based on the balance between environmental load generated because of human activities and the purification capacity of nature, that is, environmental capacity. For example, if we can identify the environmental capacity of an aquatic environment, the balance between this value and pollution load measures such as biochemical oxygen demand (BOD) and the target water quality level based on use purposes can be used to designate environmental standards.

As discussed, to build a sustainable society where the environment is protected, the scale of human activities needs to be rationally controlled so that it stays within the range of environmental capacity. One method for doing this is an approach that increases the resources productivity and lowers the environmental load generated by human activities, titled Factor Four (von Weizsäcker et al. 1988). This approach has been argued by E. U. von Weizsäcker, Amory B. Lovins, and others concerning the target efficiency for resource utilization, where "factor" is the index for considering the degree of efficiency improvement. The population of developed countries and OECD member countries is only 20 % of the global population, but these countries use 80 % of global resources. From the perspective of fair access to resources and energy, this situation is unjust. To solve this, developed nations should reduce their resource consumption to one-fourth the current value. However, simply reducing resource consumption means abandoning quality of life, which is difficult to argue. Therefore, to reach this reduction, product performance and service amount can be doubled while necessary resource input for production is halved, quadrupling the efficiency (i.e., Factor Four). Factor 10 (Schmidt-Bleek 1997) was proposed by Friedrich Schmidt-Bleek of the Wuppertal Institute of Germany in 1991. This idea aims to achieve a factor of 10 by 2050 by reducing per capita resource consumption or environmental load emissions in developed countries while improving resource productivity.

The Rio Declaration stated that mankind plays a central role in sustainable development. According to this thinking, critical to environmental protection are various technologies for measures against pollution, technology related to equipment with high energy consumption efficiency, and biotechnology that scientifically controls and uses biological resources. Such an approach is termed anthropocentric environmental protection. On the other hand, there is an argument that the goals of sustainable development must be reviewed, and environmental protection should be prioritized over human living conditions. One of these ideas is deep ecology (Alan et al. 2001; Carolyn et al. 1994), which is a philosophy and movement initiated by the Norwegian philosopher Arne Næss. The word "deep" is based on the idea that environmental problems should be tackled from their roots. In contrast, the concept that aims to achieve sustainable development using technology development is termed "shallow ecology" (to avoid the word shallow, which has a negative connotation, "reformism" may be used). The philosophy of deep ecology accepts a certain level of necessity for shallow ecology, that is, a response to environmental problems with technological development. However, current environmental problems are considered to have surpassed the capabilities of shallow ecology. Considering the roots of environmental and social problems, values that pursue materialistic richness must be revised. Furthermore, instead of living standards and materialistic accumulation, quality of life and self-realization should be desired.

## 10.2 Basic Concept of Environmental Protection

1. Precautionary of prevention

   When the scale of environmental problems becomes large, mechanisms spanning from its phenomena to its effects become highly complex; thus, it becomes difficult to predict the seriousness of future potential problems. For global-scale environmental problems, it is difficult to discuss and determine the causal relationship between human activities and environmental effects. At this stage, because of insufficient scientific knowledge, whether some of the problems would actualize remains unclear. In such cases, people may not agree to sacrifice current benefits for potential future problems. However, some irreversible environmental problems cannot be recovered to current conditions once they actualize. In such cases, there is a stipulation that the lack of complete scientific certainty cannot be used to postpone measures with high cost/effect ratio to prevent environmental degradation. This principle of decision-making related to uncertain phenomena is called the precautionary principle (History et al. 2004). In Japan's Basic Environment Plan, "precautionary measures" is one of the four ideas for guidelines of environmental measures.

2. Source reduction

   The first pollution prevention measures restricted concentrations and amounts of pollutant emissions. Waste treatment measures have also been implemented to reduce and detoxify emitted waste. As such, measures that treat existing pollutants and waste are called end-of-pipe measures. In contrast, the design of products and production methods devised to reduce the creation of pollutants and waste are source reduction (History et al. 2004). In 1991 in Japan, policies on limiting emissions and recycling were introduced at a legal level for the first time: one law was enacted to promote the use of recycled resources and one regarding waste treatment and cleaning was amended. Later, limiting emissions were prioritized with the 1994 First Basic Environment Plan and the 2000 Basic Act for Establishing a Sound Material-Cycle Society. The latter Act stipulated that waste generation from raw materials and products must be controlled as much as possible. Furthermore, waste that still has some use was defined as a circulative resource, and principles of its use and disposal were stipulated. The Basic Act prioritized limiting emissions, reuse, recycle, heat recovery, and proper disposal, in that order.

3. Polluter pays principle and extended producer responsibility

   The polluter pays principle is a principle that states that the polluter is responsible for the costs of pollution prevention measures, environmental damage caused by pollution, pollution recovery, and relief for victims of pollutants mainly generated during the production stage of products. However, the polluter pays principle does not clearly state who is responsible for the cost of preventing and remedying environmental impacts generated during product use and disposal. In other words, it is unclear whether those who use the product or those who are responsible for its environmental impact after disposal are polluters. It is also unclear whether consumers who produce garbage or producers who make products that become garbage are responsible. This has led to the idea of extended producer responsibility, which is an approach of environmental policy that states that both production and post-consumption environmental load are the responsibility of the producer (History et al. 2004). Thus, product waste treatment responsibility shifts from the municipality to the producers, and incentives are awarded for environmental considerations during the product design stage. Here, there are both physical responsibilities, such as refuse disposal, and financial responsibilities, such as bearing treatment costs. In Japan, the Basic Act for Establishing a Sound Material-Cycle Society states that extended producer responsibility is the idea that "the producer must be responsible for their own products not only during the production and use stages but also when the product has become post-use waste." This is considered an extremely important perspective for establishing a recycling-oriented society for the following reasons: (1) the producer uses parts and materials repeatedly and continuously, so they may be able to reuse and recycle these materials; (2) producers have good knowledge of the product structure and properties and can easily separate and decompose its products; and (3) efforts to select materials and structures that contribute to reuse and recycling during the design stage are encouraged.

## 10.3 Methods of Environmental Systems Analysis

Environmental problems and environmental phenomena are systematically analyzed in environmental systems analysis (Environmental Problems & Kagaku 2009). Here, we describe typical methods used in this analysis. Systems analysis is a method for evaluating phenomena rising from interaction of multiple factors by subdividing the subject to clarify the characteristics of individual factors or by comprehensively examining the whole by integrating its factors. Generally, a system that exists for a certain purpose is composed of many interacting factors. In one system, multiple subsystems exist, and subsystems harmoniously interact with each other and exist as a coherent whole.

1. Extracting factors and understanding the causal relationship

   Typical procedures used in environmental systems analysis are shown in Fig. 10.2, and Table 10.1 summarizes the main methods used for each procedure. The first procedure includes processes (a) to (b), where a series of phenomena that lead to environmental problems are considered as a system. Here, a structure exists in which humans use the natural environment and receive amenity services, change, and affect the environment; this causes humans to experience the effects on the environment (Tomitaro Sueishi and Environmental Planning Research Group 1993; Committee on Environmental Systems Japan Society of Civil Engineers 1998). As seen, the essence of environmental systems analysis includes the extraction of various factors that affect the environment from human activities, the understanding of the causal relationship between those

**Table 10.1** Methods used in environmental systems analysis

| Procedure | Method |
|---|---|
| Factor identification, causal relationship summary | For example, brainstorming, the KJ method, the ISM method, the DEMATEL method, AHP, and structural equation modeling |
| Quantification of items such as environmental load, value, and damage | For example, LCA, MFA, monetary environmental valuation, environmental accounting, material flow cost accounting, and ecological footprints |
| Model description | For example, material balance model, SD model, and micro-/macroeconomic model (e.g., econometric model, I-O model, and CGE model) |
| Calculation and evaluation of the effects of introducing environmental items such as measures and technology | Forecasting and backcasting |

factors, and structural modeling. For this purpose, methods such as brainstorming, the KJ method, the interpretive structural modeling (ISM) method, and the decision-making trial and evaluation laboratory (DEMATEL) method are used. These methods qualitatively express the structure through a diagram that summarizes the relationship between factors. Furthermore, structural equation modeling is used to quantitatively evaluate the compatibility of the generated relationship diagrams and the strength of the relationship between factors.

2. Qualitative evaluation of environmental load, value, and damage

   Next, a quantitative evaluation of environmental load from human activities and its impact on the environment is necessary. A representative method for the quantitative evaluation of environmental load is termed life cycle assessment (LCA), which evaluates environmental load created in a series of processes (life cycle) such as resource extraction, material manufacturing, production, distribution, sales, use, recycling, and disposal of products, services, or social capital. By evaluating the environmental load using the LCA, products and services with smaller environmental loads can be designed and developed. A typical LCA procedure consists of four stages: (1) setting goals and the evaluation range, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

   To systematically understand the flow of materials and energy between the natural environment and economic activities as well as between economic entities (Moriguchi 2003), material flow accounting (MFA) is used. Under MFA, area and period are first sectioned. Then, the total input of materials into, flow of materials within, and total emission of materials outside of the area are estimated. In addition, using the data collected through the MFA, resource use efficiency is analyzed, termed material flow analysis. This method is used to identify waste of natural and other resources in an economy that cannot be identified in standard economic statistics. MFA is discussed in detail in another chapter.

A method that evaluates the size of environmental load and impacts considering its monetary value may be used. For example, the travel cost method, the hedonic method, and the contingent valuation method (CVM) are used for monetary evaluation of environmental values. Details of monetary evaluation of the environment are explained in another chapter. Under environmental accounting, environmental protection costs of business activities and the effects of these activities are quantitatively measured in monetary or physical units and then summarized and communicated. Environmental accounting focuses on wasted resources and energy loss generated during the production process and integrates material weight and environmental load emission. Then, material flow cost accounting is conducted to comprehensively evaluate the cost used for the loss in the production process, including the material, processing, and facility costs considered negative production costs. Integrated indexes that summarize multiple environmental loads and ones that combine economic and environmental indexes have also been developed.

3. Description of the model

Next, a model is designed to quantitatively evaluate the connection between human activities and environmental impact. The appropriate model is chosen depending on the type of environment, goal, and policy measures. The forerunner of the environmental model is *The Limits to Growth* by the Club of Rome (Meadows 1972). Their model, the World3 model, considers various elements, such as population, industrial production, food production, and pollutant emissions, and their interaction structure is modeled using system dynamics (SD). Econometric models, input-output (I-O) models, and computational general equilibrium (CGE) models are examples of economic and material balance models that describe occurrence, movement, and alteration of environmental load. These models are sometimes used in combination with environmental load tables prepared using LCA and MFA (Nakamura 2007).

4. Scenario analysis (forecasting/backcasting)

Finally, scenario analysis is conducted to predict the future environment (Fig. 10.3c). In scenario analysis, possible or ideal futures are tentatively visualized and quantitatively confirmed with model analysis. Here, there are two methods of preparing scenarios: forecasting and backcasting. Forecasting is a method that predicts the future deductively from current conditions and is also called trend analysis. In scenario analysis with forecasting, effects of multiple alternatives are evaluated for each scenario in the model (e.g., policy and technical progress), and it is determined whether the environmental index value reaches its final target level. Backcasting works backward from the goal. In this method, the ideal future and goals are determined, and necessary individual technology, systems, and organizations are considered. The "ideal future" set for backcasting is not singular, and multiple futures are visualized depending on their social acceptability and the concept of environmental protection. For example, a society with highly advanced technology (e.g., anthropocentric environmental protection) or one that values coexistence with nature may be visualized, and values of economic development and material wealth are

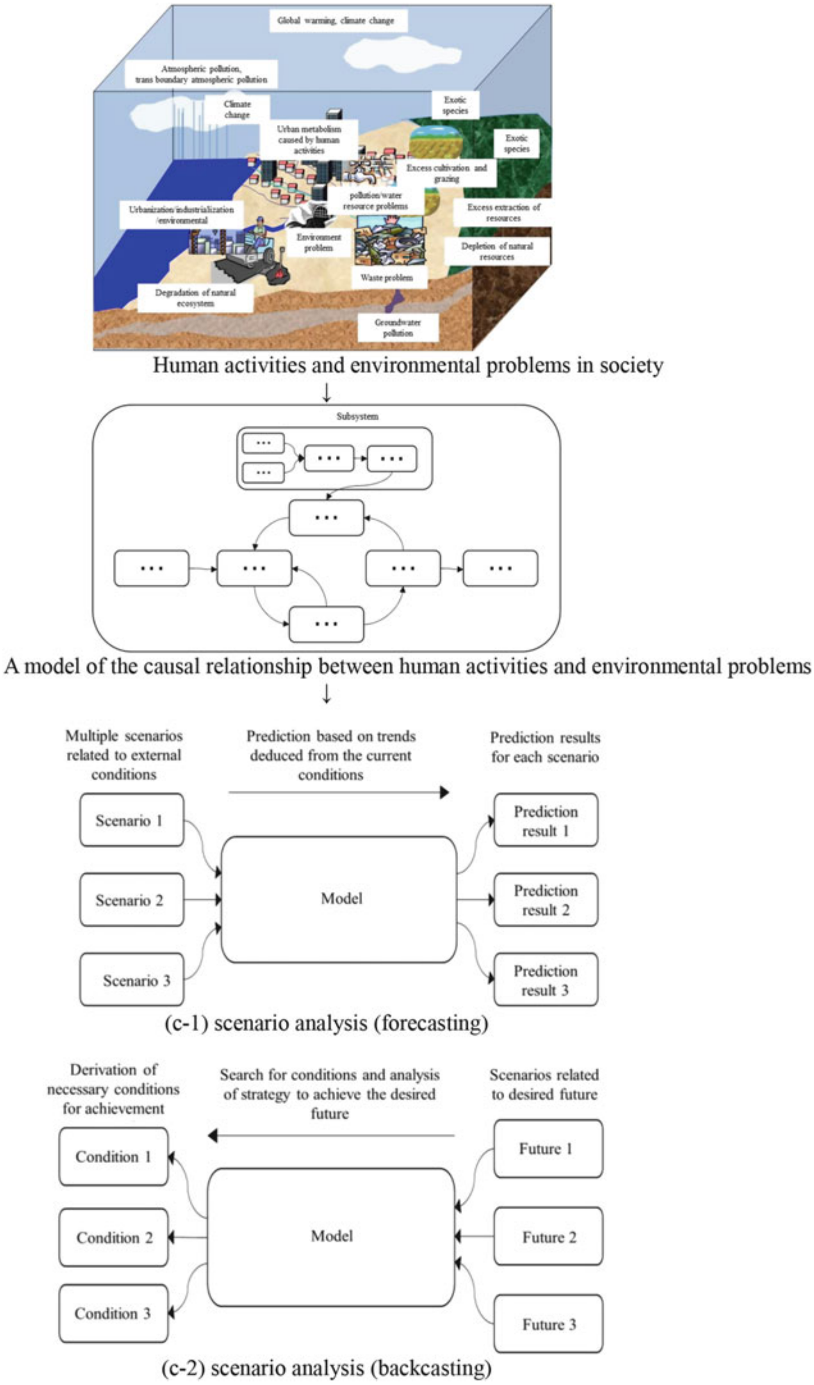


**Fig. 10.3** Typical procedures of environmental systems analysis

revised. Critically, backcasting does not eliminate the potential that future societies may achieve by obsessing about ideals.

## References

Committee on Environmental Systems Japan Society of Civil Engineers (ed) (1998): Environmental systems – concept and application method. Kyoritsu Shuppan Co., Ltd., Tokyo
Daly HE (1990) Toward some operational principles of sustainable development. Ecol Econ 2(1):1–6
Drengson A (2001) Deep ecology – environmental philosophy from the way of living (co-edited and trans: Inoue Y). Showado, Kyoto
Imura H (2009) Systematic approach to environmental problems. Kagaku Doujin, Kyoto
Kurasaka H (2004) Environmental policy – history, principle, and method of environmental policy. Shinzansha, Tokyo
Meadows DH (1972) Limits of growth – the club of Rome. Crisis of Humanity Report, Diamond Inc., Tokyo
Merchant C (1994) Radical Ecology – in search of comfortable world (trans: Kawamoto T, Sudo J, Mizutani H). Sangyo Books
Moriguchi Y (2003) Material flow data book – resource flow in the World Around Japan. National Institute for Environmental Studies, Tsukuba
Nakamura S (2007) Life cycle input output analysis. Waseda Institute of Political Economy. Research Monographs, Tokyo
Schmidt-Bleek F (1997) Factor 10 – eco-efficiency revolution (trans: Sasaki K). Springer-Verlag Tokyo
Tomitaro Sueishi and Environmental Planning Research Group (1993) Environmental planning theory – as a Foundation of Development and Protection of Environmental Resources. Morikita Publishing, Tokyo
Ueta K (1996) Environmental economics. Iwanami Shoten, Tokyo
von Weizsäcker EU, Lovins AB, Lovins LH (1988) Factor four: doubling wealth, halving resource use – a report to the club of Rome. Energy Conservation Center, Japan