AIM/end-use Model and Its Application to Forecast Japanese Carbon Dioxide Emissions.

Mikiko Kainuma[a], Yuzuru Matsuoka[b] and Tsuneyuki Morita[a]

[a] Global Environment Division, National Institute for Environmental Studies,
16-2 Onogawa, Tsukuba 305-0053, Japan
Tel: +81-298-50-2422, Fax: +81-298-50-2524, e-mail: mikiko@nies.gi.jp

[b] Faculty of Engineering, Kyoto University,
Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

Abstract: AIM (Asian-Pacific Integrated Model) has been developed for predicting greenhouse gas emissions and evaluating policy measures to reduce them. Two socio-economic scenarios were assumed and CO_2 emissions were predicted based on these scenarios and policy intervention assumptions. It is found that mitigating CO_2 emissions by 6% to the 1990 level without scaling back productive activities or standards of living in Japan is possible. However, if one relies on the market mechanism alone, it cannot be done. The analysis has shown that it is indispensable to introduce new policies and measures such as carbon tax and subsidies.

Keywords: Economics, Energy, Environment, Technology, Simulation

1. INTRODUCTION

Global warming has great impact on the world socio-economy, and it is expected that counter-measures against it will impose a heavy economic burden. To promote countermeasures against it, it is necessary to predict the amount of greenhouse gases emitted or absorbed by each country and the effects resulting from the introduction of measures to mitigate emissions. To predict and judge these issues, the development of an integrated simulation model is indispensable.

The AIM model (Asian-Pacific Integrated Model) estimates the emission and absorption of greenhouse gases in the Asian-Pacific region and judges the impact they have on the natural environment and socio-economy (Matsuoka et al.,1995). It aims to contribute policy-making against global warming and its evaluation. The AIM model consists of a greenhouse gas emission model (AIM/emission), a climate change model (AIM/climate) and an impact model (AIM/impact). The AIM/end-use model used in this study is a part of AIM/emission model.

A number of energy consumption-based greenhouse gas emission models have been developed (Morita et al., 1994) and they can be classified into two types. Those that are called "top-down models" start with an economic model using prices and elasticity as economic indices and present the relations among energy consumption, production and economic indices intensively. (Kainuma et al., 1998). For a long-term forecast, a top-down world model based on market equilibrium that forecasts world economic activity and change is indispensable. The other type of models, which is called "bottom-up models", focuses on the final consumption of energy based on actual energy use and the way energy services are performed. Based on detailed descriptions of technologies, a model calculates the total energy consumption and production from the "bottom-up". Among the many advantages of "bottom-up models", the most important is that their results can be interpreted clearly because they are based on detailed descriptions of changes in human activities and technologies. When introducing new policies, these bottom-up models, with their tangible results and explicability, are indispensable for explaining the directions and effects of policies to politicians.

Bottom-up models have been developed in two directions. One is for analyzing more efficient technologies and their combinations by focusing on the supply and conversion of energy.

MARKAL (Berger *et al.*, 1987; Fishbone *et al*, 1981; Manne and Wene, 1992), which was developed primarily by the International Energy Agency, and EFOM, which was developed in France, are representative of this field. The other direction taken is for calculating how changes in the lifestyles of each sector influence energy demand in a bottom-up way, by focusing on energy demand and consumption. These models are usually called 'end-use models'. Among this type of model, MEDEE (Lapilonne, 1985) developed in France and LEAP from the Stockholm Environmental Institute (Lazarus *et al.*, 1993) are the most notable. MESSAGE (Messner et al., 1997) developed by IIASA is also a typical end-use model focusing on technologies. However, the development of end-use energy-technology models, which analyze more efficient energy technologies and their combinations using energy demand and consumption, has been slow.

To reduce CO_2 emissions in Japan, it is very important to identify what kinds of energy conservation technologies will be used to what extent, so the development of an end-use energy-technology model was necessary. The AIM/end-use model is exactly this type of model and provides a new direction not available with previous bottom-up models. The AIM/end-use model can calculate the changes in energy consumption from technological substitution caused by changes in energy prices, in a bottom-up way. Thus, it is possible to evaluate not only the efficiency of each individual policy, but also the effect when various policies are combined. By linking the technology selection model with the energy demand model, it is possible to estimate energy efficiency improvements based on the actual situation for each technology.

The AIM/end-use model is used to predict future CO_2 emissions based on socio-economic assumptions. It is found that it is possible to mitigate CO_2 emissions without scaling back productive activities or standards of living in Japan. However, if one relies on the market mechanism alone, it cannot be done. The analysis has shown that it is indispensable to introduce new policies and measures such as carbon tax and subsidies.

2. STRUCTURE OF THE AIM/END-USE MODEL

As shown in Figure 1, the AIM/end-use model first estimates energy service demands based on socio-economic factors such as population, economic growth, industrial structure, and lifestyle, and then calculates what kind of technology will be used to what extent (Hibino *et al*., 1996). To compare and consider service technologies, detailed technological data and energy data are prepared. Once the kind of service technology to be used is known, the model calculates the energy necessary to provide the energy services and the amount of CO_2 emissions produced when each type of service technology operates.

2.1 Elements of end-use model

The AIM/end-use model comprises an energy service system which connects energy supply and energy service demands and links them with technological information about service technologies. The system comprises four types of elements: final energy services, external energy, service technologies and internal services/energy.

A final service is one that is produced by a set of service technologies and supplied to outside of the system. An energy service is classified into a final service and internal service. A service that is used in the system is called an internal service explained later. Examples of final services are steel products and papers in the industrial sector, and cooling, heating, and lighting in the residential sector. The final service demands are estimated based on socio-economic information such as population, economic growth and industrial structure.

A service technology supplies more than one energy service by consuming more than one type of energy. The most important judgement made in the model is that of selecting service technologies. What kinds of technologies are used depends on introduction and running costs. For example, when a carbon tax is introduced, one introduces energy-saving technologies to save energy costs. If the initial cost of energy-saving technology decreases due to the introduction of a subsidy, the introduction of that technology will be promoted.

External energy is one that is used to operate service technologies. Service technologies use different types of energy such as electricity, coal, oil and gas to produce energy services. Energy that is partly or totally generated in the system is called internal energy and is not included in external energy. External energy includes goods that are not usually categorized into energy, but are used in the system and supplied from outside of the system. Iron ore and limestone used in the steel industry are examples of external energy that are not usually classified into energy.

Internal service/energy is one that is generated and used in the system. An internal service that is produced by a service technology is an internal energy to another service technology in the system. Electricity generated by a co-generation and hot coke generated by coke oven that are not final products are examples of the internal services. They are also internal energy because they are used in the system.

An example of end-use model is shown in Figure 2. This figure shows the structure of the Japanese iron and steel industry model. This model considers three types of steel-making processes; the blast furnace process, the electric arc furnace process and the smelting reduction process. The blast furnace and the electric arc furnace are operating now. The smelting reduction method is an innovative iron making process and is now under development.

In the steel industry, the final service is the steel products. These products are produced with several kinds of technologies by using external energy. Many kinds of internal services/energy are also produced in the steel making process. There are several alternative technologies in each process. Which technologies, conventional technology or energy-saving technology should be used is determined based on costs.

2.2 Technology selection process

To decrease CO_2 emissions, it is key what kind of energy-saving technology one can introduce to what extent from an end-use point of view. The AIM/end-use model focuses on the fact that substitution technology will be available according to energy price fluctuation and estimates energy efficiency and energy consumption on the basis of each technology. Therefore, it is possible to evaluate the effectiveness of each policy or combined various policies.

The model provides for a combination of service technologies to be used in the total system so as to minimize the total cost of supplying energy services. The total cost consists of purchase costs, running costs, emission dues, and other related costs. The total cost is expressed in two ways: ALC (Annualized Life-cycle Cost) and PTM (Payback Time Method). ALC converts a purchase price to an annual cost by considering repayment period and a discount rate. PTC compares initial costs of service technologies based on payback time. The annual cost by the ALC method is calculated as follows:

$$c_{i(ALC)} = P_i \cdot [P \rightarrow M]^{q}_{L_i} + \sum_{k=1}^{n} E_{i,k} \cdot p_k \qquad (1)$$

where, P_i is a present value of the technology i including every cost except for energy costs. $[P \rightarrow M]^{q}_{L_i}$ is a capital recovery factor that converts a purchase price to an annual price. $E_{i,k}$ is amount of the k-th energy consumed by the technology i, n is the number of energy types, p_k is a price of the k-th energy type. A capital recovery factor is calculated as follows:

$$[P \rightarrow M]^{q}_{L_i} = \frac{q(1+q)^{L_i}}{(1+q)^{L_i} - 1} \qquad (2)$$

where, q is an interest rate, L_i is a lifetime of the technology i.

The annual cost by PTM method is calculated as follows:

$$c_{i(PTM)} = \frac{P_i}{\min(T, L_i)} + \sum_{k=1}^{n} E_{i,k} \cdot p_k \qquad (3)$$

where, T is a standard payback time.

To compare and evaluate technologies, it is necessary to know the detailed information of service technologies. A service technology is characterized by its type, its technological level and its introduced year. A group of service technologies that have the same characteristics is called a cohort. Each cohort is characterized by its technological factors and cost coefficients. There are several technological factors such as the amount of service performed and the amount of energy consumed by a unit of technology and its remaining lifetime (usable years).

The evaluation method differs depending on whether the technology is already at hand or not. Costs consist of fixed costs and maintenance costs such as fuel costs. Fuel costs accrue continuously every year, but fixed costs are necessary only at the time when one buys a technology. Since one uses the service technology for a number of years, one looks at the future and compares prices when one considers the introduction of technology. There are two ways of making this comparison.

When one does not have a technology, or when the time has come to change a technology one already has, one sums the introduction costs and the running cost, and chooses the cheapest technology.

If one already has a technology and the time to change it has not come yet, one looks at the operating costs of the old technology. When one considers a new technology, one sums the introduction cost and the operating cost. When one considers upgrading the old technology, one sums the improvement cost and the operating cost. Comparing these costs, one chooses the most economic technology.

3. AN ILLUSTRATIVE EXAMPLE

Let us explain how the model selects technologies by a simple example. Figure 3 shows files used for input and output data. Technology data is essential for the end-use model. Historical share of technologies and future upper limit of share are also necessary to estimate future share of technologies. Energy prices and energy constraints are used to determine which technologies should be used. Carbon emission factor is used to estimate carbon dioxide emissions. Based on these data and service demand scenarios, technology share and supplied services by technologies are determined in the model. Then energy consumption and carbon dioxide emissions are calculated.

Assume there are two technologies, A and B that produce same energy service. The hypothetical characteristics of the technologies are shown in Table 1. Each unit of technology supplies a unit of service. A unit of technology A consumes 3 tera cal/period and a unit of technology B consumes 1 tera cal/period. The lifetime of each technology is 5 periods. Assume a price of technology A is 100 thousand $ and B, 150 thousand $, respectively. It is assumed that technology B is not available initially and supply of technology B is limited up to 30 units per period. It is also assumed that energy price is 17 thousand $/tera cal and CO_2 emission factor is 82 ton carbon/tera cal. Initial service demand is assumed to be 100 units and service demand will increase by 5% per period.

Table 2 shows how the technologies are introduced at each period from 0 to 5th period. All services are supplied by technology A initially. At the next period, extra service demand should be supplied by either technology A or B. Assume that PTM is used and payback time is two years. The price of existing technology A is 51(3 x 17) thousand $. The selection price of introducing technology A is 101 (100/2+51) thousand $ and that of technology B is 92 (150/2+1*17) thousand $. To supply 5 service units at the first period, technology B is introduced. At the 5th period, the lifetime of existing technology A is expired and new technologies should be introduced to supplement the expired technology. As technology B can only be introduced up to 30 units per period, technology A is also introduced by 76 units.

Figure 4 shows the number of technologies introduced and Figure 5 shows the CO2 emissions. As service demand increases, technology B is introduced. When the expire time of technology A comes, technology B is introduced up to 30 units. At the 13th period, although energy demand is increased by 1.9 times to the initial period, CO2 emissions is increased only by 1.2 times because of introducing energy-saving technology B.

4. CASE STUDIES IN JAPAN

4.1 Socio-economic assumptions

The AIM/end-use model is applied to estimate future CO_2 emissions and to analyze possible CO_2 reductions in Japan. When one looks at Japan over the long-term, that is, throughout the first half of the next century, one should bear in mind the considerable uncertainty regarding anticipated changes in the social structure, particularly with regard to demographic trends. For example, the Japanese population will reach a peak in 2010 and then begin to decrease. In addition, the post-war baby boom generation will be approaching retirement age at around that time. It is possible that such changes will greatly affect the life style of the people and the direction of the nation's economic development.

Furthermore, if the trend toward economic globalization continues during the next century, by 2030 China and other East Asian nations can be expected to reach the economic standard attained by Japan in the 1970s. As a result, it is easy to predict that the industrial structure of Japan will change greatly. On the other hand, it has also been predicted that wide-spread environmental impacts, such as acid rain from the burning of coal in China, will become apparent in East Asia from the beginning of the next century. Consequently, it seems extremely likely that the investment in countermeasures against environmental pollution will increase rapidly and that the cost of the required technologies will decrease very quickly.

This type of structural change will have significant impact on the scale of future CO_2 emissions. However, the extent of such changes is difficult to predict. For this reason, it is necessary to adopt a perspective that incorporates a sufficient degree of uncertainty.

Let us now assume two scenarios for Japan’s future. The first scenario is one in which little structural change occurs and present consumption-dependent lifestyle as well as existing manufacturing activities are maintained as much as possible. We call this scenario the “contemporary materialistic nation scenario.” The other scenario is one in which the Japanese social structure undergoes a radical shift toward a production system and lifestyles that take intellectual activities seriously, and in which structural changes occur on a significant scale. We call this the “creative/knowledge-intensive nation scenario” (AIM project team, 1997).

If one assumes for each of these scenarios parameters in respect of an economic growth rate, an industrial structure and goods shipments, required office space, transportation, et., the projected amount of CO2 emitted can be estimated. On the basis of these assumptions, we have conducted computer simulation analysis.

4.2 Forecasts of CO2 emissions

Figure 6 shows the future perspective of CO_2 emissions in the case of the “contemporary materialistic nation scenario” and the “creative/knowledge-intensive nation scenario.” Three kinds of mechanisms for introducing technologies are assumed: frozen, market and intervention cases.

Frozen technology means that technologies at 1990 level continue and new technologies will not be introduced into the market. CO2 emissions will increase by 24 % to 26 % to 1990 level by the year 2010 in the frozen case. Introduction of new technology is anticipated.

The market case means the cheapest technology spreads based on the market mechanism. In this case, the increase of CO2 emissions will be between 13 % to 15 % by the year 2010. Even if the energy-saving technology is somewhat expensive, the spread of the technology proceeds because it is possible to recover the costs through fuel savings in a short period of time.

In either case, if no special countermeasures such as government intervention occurs, the amount of CO_2 emissions will continue to increase. Quick actions are necessary to stabilize and reduce CO_2 emissions.

The intervention case assumes government intervention scenario. In the case of Figure 6, it is assumed that 30,000 yen (US$ 250) per ton of carbon to promote the introduction of technologies. Or, if we assume that the tax is to be returned to companies and households in the form of subsidies for introduction of energy-saving and recycling technology, a carbon tax of 3,000 yen (US$25) per ton of carbon would be sufficient. This would add the equivalent of 2 yen (US$0.017) to retail price of a liter of gasoline and would accelerate the introduction of energy-saving technology across a variety of fields.

Through such measures, it would become possible to reduce Japanese CO_2 emissions by the year 2010 by 7.6% as compared to 1990 level in the case of the "creative/knowledge-intensive nation scenario", and 6.1% in the case of the "contemporary materialistic nation scenario". Even without decreasing productive activities and lowering living standards, a reduction in CO_2 emissions is possible.

5 CONCLUDING REMARKS

In the Kyoto meeting on climate changes, they agreed to reduce greenhouse gas emission of the developed countries by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012. The target is different region by region. Japan has to reduce emissions by 6 per cent of the 1990 level. The AIM/end-use model was used to estimate how much CO2 reduction is possible. Two future socio-economic scenarios and three kinds of mechanisms for introducing energy-saving technologies are considered. CO2 emission projections will change depending on mechanisms for introducing energy-saving technologies more than assumed differences of socio-economic scenarios.

It is possible to decrease CO_2 emissions without scaling back productive activity or reducing living standards in Japan. However, if one relies on the market mechanism alone, this will not occur. Our analysis clearly shows that it is necessary to introduce new policies and measures such as a carbon tax and increased subsidies for introducing energy-saving technology.

If Japan attempts to reduce CO_2 emissions even further, the costs will inevitably become larger. These will certainly be costs for the firms and households that have to bear the burden of reducing CO_2 emissions. However, it is an increase of effective demand for the producers of energy-saving technology. It is estimated that the indirect cost of CO2 emission reductions for Japan as a whole will be extremely small as a result of the growth of environment-related industries. Moreover, the business opportunities for these industries will increase further as joint projects with developing countries to reduce CO_2 emissions are implemented.

The likelihood is high that in the next century, social-structural change will transform Japan from a "contemporary materialistic nation" to a "creative/knowledge-intensive nation." This transformation will make it relatively easier to control CO_2 emissions and take countermeasures to protect the global environment. It can be argued that the social system of Japan is changing in such a way as to make it more advantageous to introduce environmental policies.

We are collaborating with several institutes and universities in the Asia Pacific region and the AIM model has been used to provide country base greenhouse gas emissions in these regions.

The AIM training program has been started in 1997 and training workshops were held both at Beijing, China and Ahmedabad, India sponsored by the Asian-Pacific Network Program. It is hoped to enable new researchers in the partner countries to join the AIM team to gain modeling and analytical skills. These skills can then be used to direct the model to evaluate a wide range of policies in each country.

ACKNOWLEDGEMENT

This research is funded by the Environment Research Program of the Japan Environment Agency. We are grateful to Masaya Yoshida, Go Hibino and Hisaya Ishii of the Fuji Research Institute Corporation, and Kenta Mizuno of Wakachiku Construction for their extensive supports.

REFERENCES

AIM Project Team (1997) *Long-term CO2 Emission Outlook in Japan*. AIM Interim Paper, IP-97-03, NIES, Tsukuba.

Berger, C., Haurie, A. and Loulou R. (1987) *Modeling Long Range Energy/Technology Choices: The MATKAL Approach*, GERAD, Montreal, Canada

Fishborne, L.G. and Abilock, H. (1981) 'MARKAL, A linear-programming model for energy systems analysis: technical description of the BNL version' *Energy Resear*ch **5** 353-357

Hibino, G., M. Kainuma, Y. Matsuoka and T. Morita (1996) *Two-level Mathematical Programming for Analyzing Subsidy Options to Reduce Greenhouse Gas Emissions*. II ASA working paper, WP-96-129, IIASA, Austria.

Kainuma, M., Y. Matsuoka and T. Morita (1998) Analysis of post-Kyoto scenarios: the AIM model, EMF Workshop on Climate Change Impacts and Integrated Assessment, Snowmass, Colorado, August, 1998.

Lapillonne, B. (1985) *The MEDEE-S Approach for Energy Demand Evaluation in Developing Countries*, Report EUR 9971FR, General Direction Science, Research and Development, Commission of European Communities, Bruxelles

Lazarus, M. et al. (1993) *Towards a Fossil Free Energy Future, The Next Energy Transition,* A technical analysis for Greenpeace International, Stockholm Environment Institute - Boston Center, MA

Manne, A.S. and Wene, C.O. (1992) *MARKAL-MACRO: A Linked Model for Energy-Economy Analysis*, BNL-47161, Brookhaven National Laboratory, Upton, New York

Matsuoka, Y., M. Kainuma and T. Morita (1995) Scenario analysis of global warming using the Asian Pacific Integrated Model (AIM). *Energy Policy*, **23** (4/5), 357-371.

Messner, S., A. Golodnikov and A. Gritsevskii (1997) A stochastic version of the dynamic linear programming model MESSAGE III, *Energy*, 21(9), 775-784.

Morita, T., M. Matsuoka, I. Penna and Kainuma (1994) *Global Carbon Dioxide Emission Scenarios and their Basic Assumptions - 1994 Survey* -, Center for Global Environmental Research, CGER-I011-'94, Tsukuba, Japan.

Table 1 Characteristics of Technologies A and B

	A	B
Service supply/Technology unit	1 (Service unit)	1 (Service unit)
Energy consumption/Technology unit	3 (Tera cal/period)	1 (Tera cal/period)
Lifetime	5 Period	5 Period
Initial price/Technology unit	100 (1,000 $)	150 (1,000 $)

Table 2 List of technology share from 0 to 5th period.

Period	Service Units	Technology Units	Technology	Lifetime
0	100	100	A	5
1	105	100	A	4
		5	B	5
2	110	100	A	3
		5	B	4
		5	B	5
3	116	100	A	2
		5	B	3
		5	B	4
		6	B	5
4	122	100	A	1
		5	B	2
		5	B	3
		6	B	4
		6	B	5
5	128	5	B	1
		5	B	2
		6	B	3
		6	B	4
		76	A	5
		30	B	5

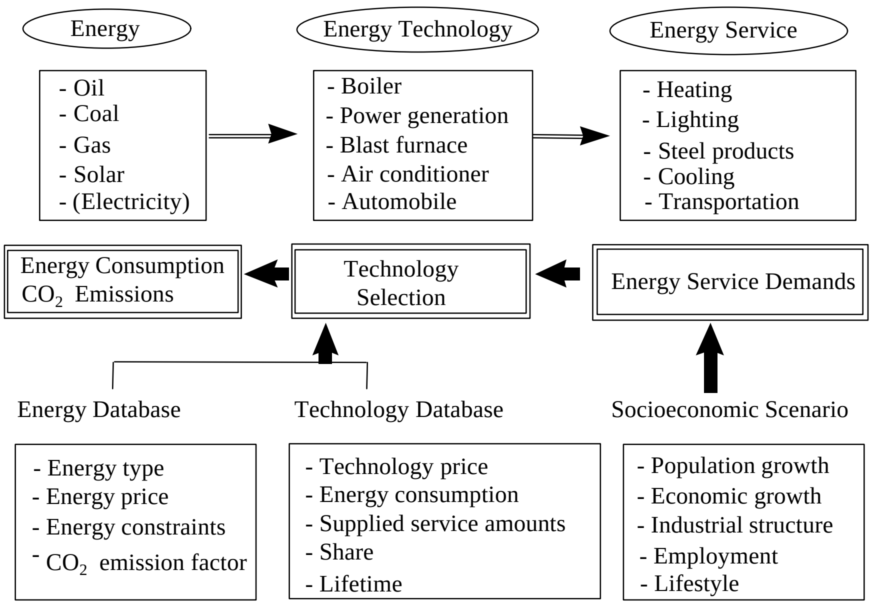

Figure 1 Structure of the AIM/end-use model

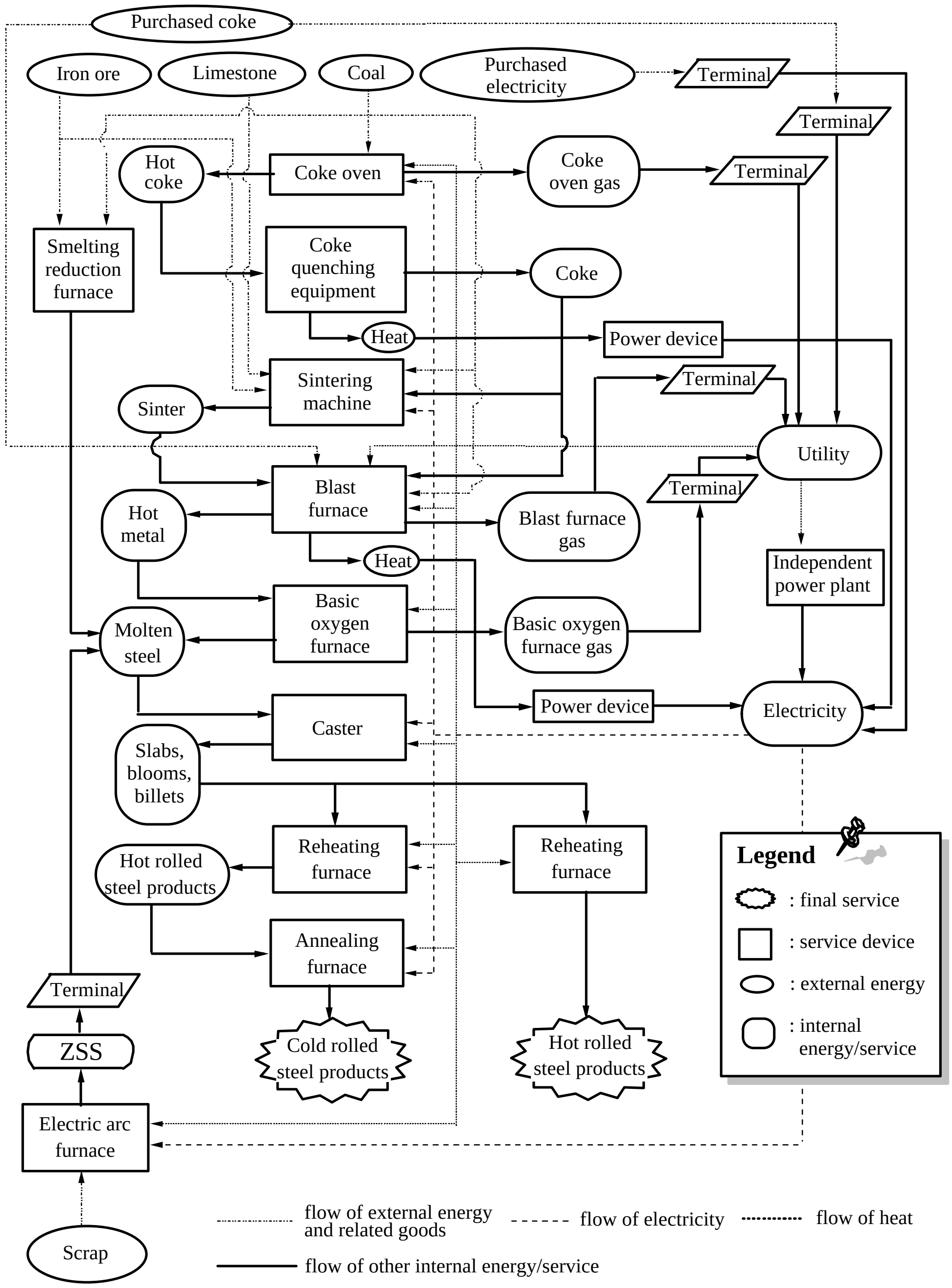

Figure 2 Structure of the Japanese steel industry model

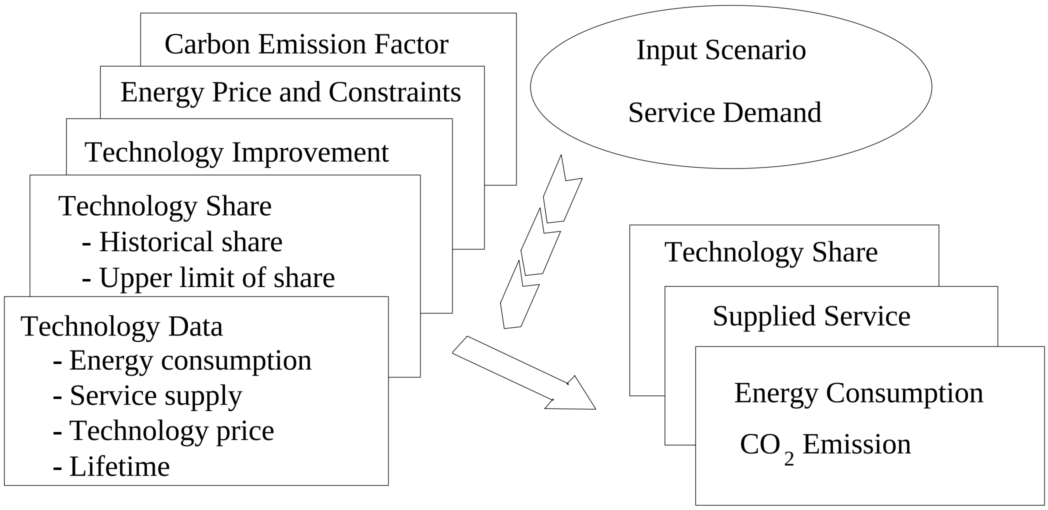

Figure 3 Input and output files of the AIM/end-use model

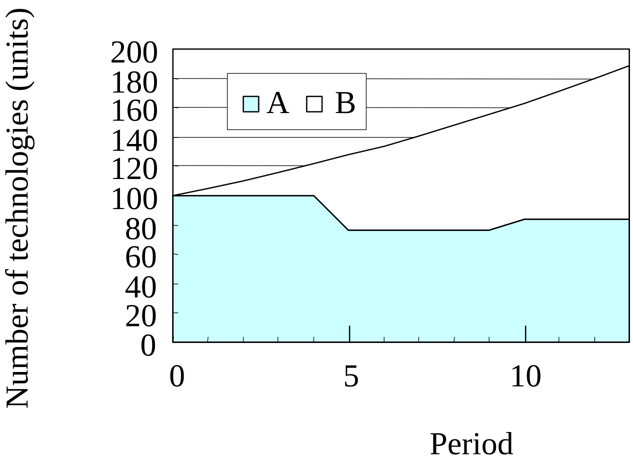

Figure 4 Number of technologies introduced

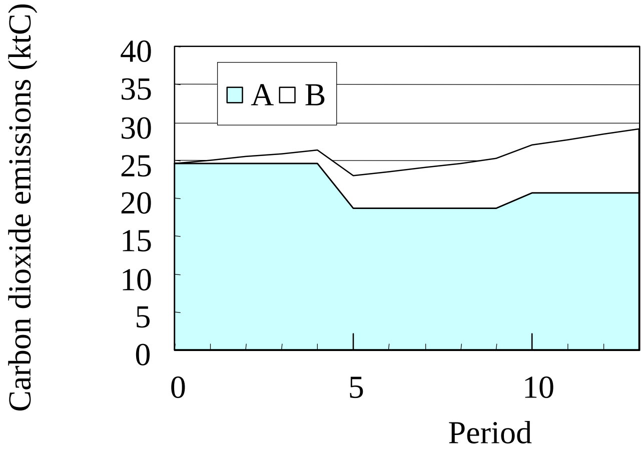

Figure 5 Carbon dioxide emissions

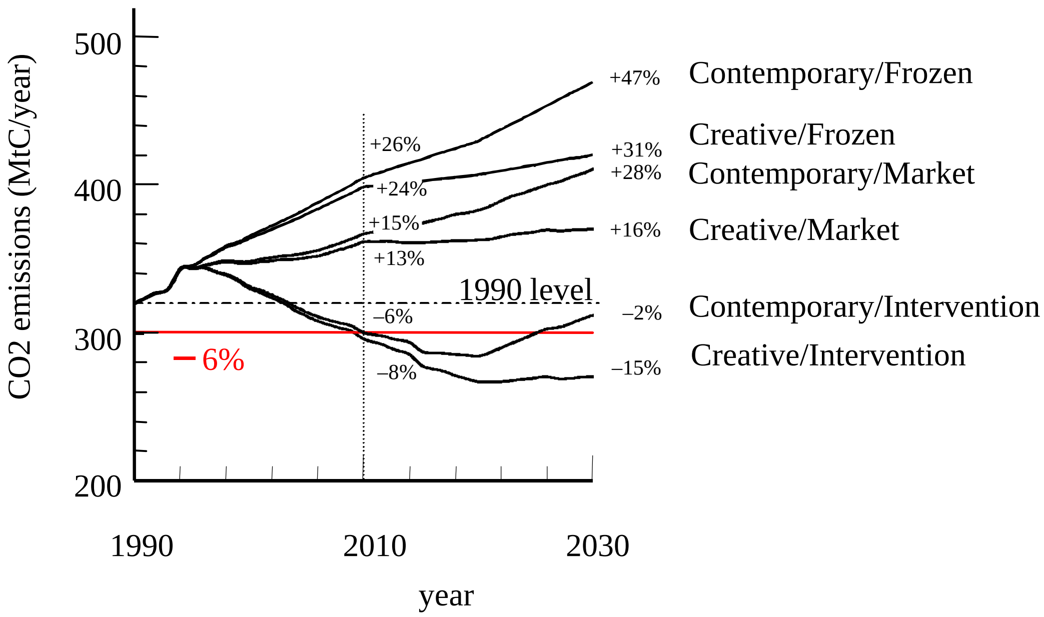

Figure 6 Forecasts of Japanese carbon dioxide emissions

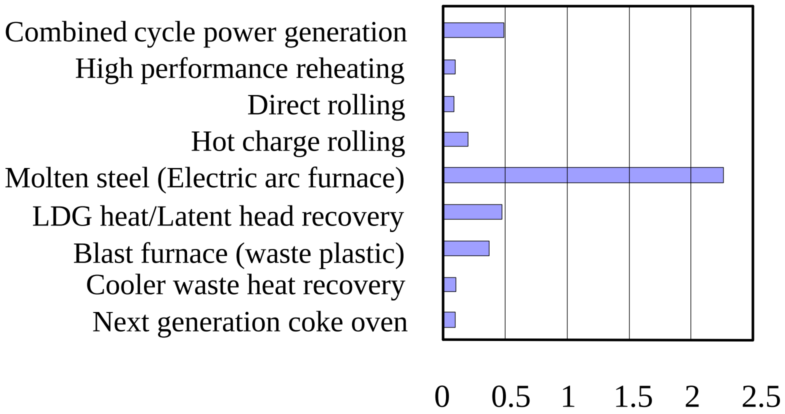

Figure 7 Reduction of Carbon Dioxide Emission (MtC)