IR-1 Development of a Global Model for Sustainable Development

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Total Budget for FY 1990-1994 81,369,000 Yen (FY1994 15,071,000 Yen)

Abstract This five year program investigated global environmental problems using the results and outcomes of the Global Environmental Research Program and other international research programs, and examined some of the basic conditions for sustainable development. The program produced and used a variety of models to analyze these problems and develop new scenarios that take into account conditions for sustainable development and relationships within the global economy. The work completed during this time is described.

Key Words Sustainable Development, Framework Model, Global Material Flow, Economic Model, Macro-economic Impact

1.Introduction

Global environmental problems such as global warming, depletion of the ozone layer, tropical rainforest destruction and desertification are closely related to each other and to global socioeconomic activities. In order to analyze comprehensive measures for solving these problems, it is necessary to clarify the overall structure of the problems and the trade-offs available between global environmental protection and socioeconomic development.

This study aimed to investigate the global environmental problems based on the results and outcomes of the Global Environment Research Program and international programs such as IGBP and IPCC, and to determine the basic conditions for sustainable development by examining various relationships within the global economy.

2. Environment Framework Model

Recently, much work has been done to assess policy options for sustainable development. However, there have been some difficulties in communicating policy needs and scientific knowledge between policy makers and researchers. The Environment Framework Model (EFM) is a communication platform for assessing sustainable development policies, and shows decision makers which are important.

As shown in Figure 1, a simple matrix system is used to clearly explain the most recent and often complex information. A knowledge based system, based on this matrix cohort, is used to identify each research topic and gain access to all relevant information. A linear programming method finds the comparative importance of each phenomena (environmental issue). A method based on fuzzy set theory identifies which items of uncertainty are the most useful to reduce.

Using the Simple Matrix System, the EFM attempts to explain the major processes of human - environment interaction, including the Basic Production Requirement Process and the Production Input Requirement Process. Each matrix is formulated using a Cobb-Douglas Type Function.

To compare the degree of environmental and other constraints on development, the EFM uses an optimization method. The maximized GDP subject is estimated subject to various

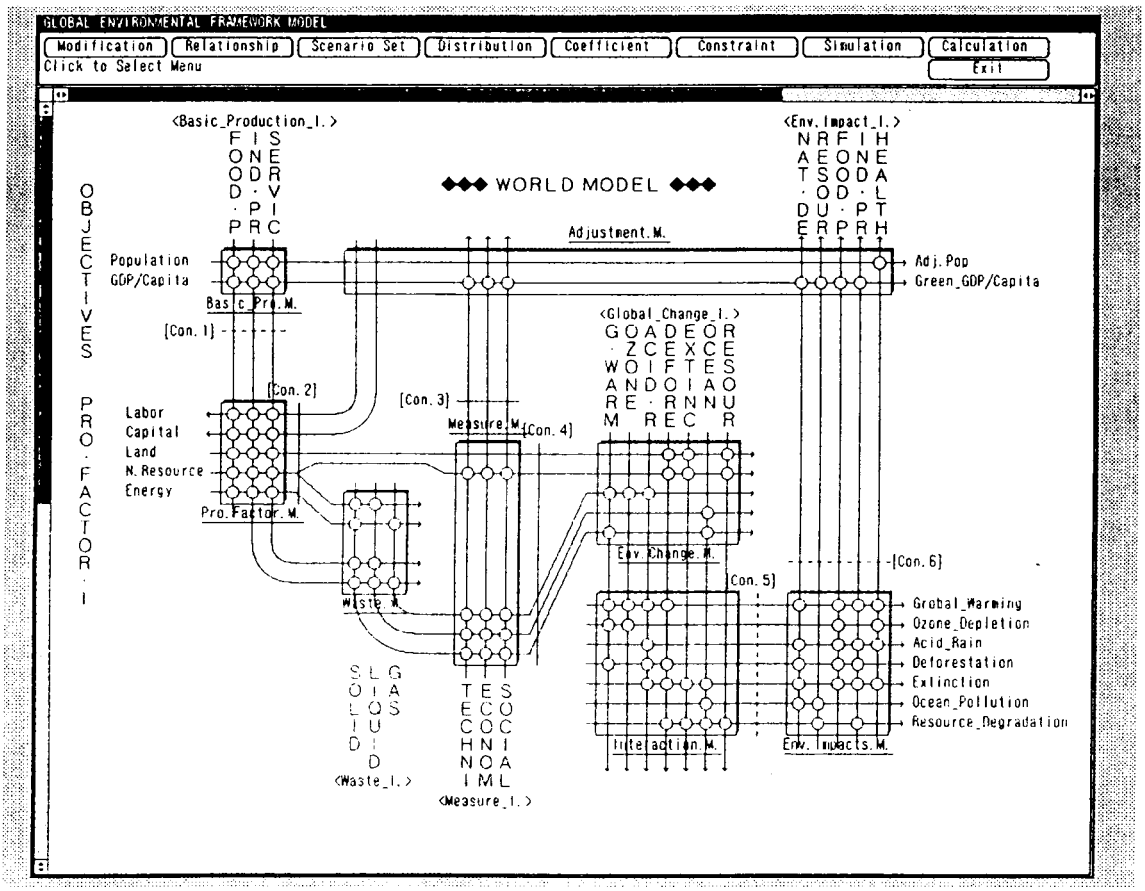

Figure 1. A structure of framework model

constraints. It can estimate the shadow price of each constraint, and when the shadow prices are compared, the severity of the constraints can be identified.

Even the current preliminary version of the EFM can be used as an effective communication platform for analyzing sustainable development proposals. Based on a specific scenario of future development, the EFM can estimate the necessary production levels, resource and energy use, inevitable waste emissions and other environmental change and impact levels. Assuming stated constraints of resources and environmental conditions, the EFM can estimate the potential level of economic development. Using these constraint assumptions, the EFM can estimate the comparative severity of each constraint and the importance of each resource and environmental condition.

The EFM is still under development, but has a very high potential for application to environmental policy analysis. This model will be applied to the ECO ASIA Long-term Project as a tool for analyzing each country's situation.

3. Global Material Flow Models

In order to analyze the interactions among global environmental issues, two global material flow models were developed - an atmospheric transport and chemical reaction model to analyze the interaction between various air pollution problems, and a water pollution transport model.

The atmospheric and chemical reaction model has a resolution of 5 degrees and is comprised of a transport model based on a model produced by Russell and parameters fixed by Heimann, and an original chemical reaction model with Ikeda's parameters. Using this model,

the global diffusion of anthlopogenic sulfur compounds was simulated.

The water pollution transport model is comprised of two models - an oceanic pollution model and a terrestrial water pollution model. The oceanic transport model was developed by improving the oceanic general circulation model of GFDL. The terrestrial transport model is an original model developed using global 5 minute grid altitude data, and various geographic information systems.

These models were used to simulate the spatial diffusion of water pollutants originating from Japan's land base.

4. A Review of Global and Domestic Economic Models

Twelve studies have been conducted on the mitigation costs for reducing CO_2 emissions in Japan. They estimate the carbon tax rates necessary to stabilize CO_2 emissions in Japan, and also their cost or economic impacts.

All but one are top-down economic models. Five are medium-term prediction models and six are long-term equilibrium models, including dynamic optimization models and general equilibrium models. Only one is a bottom-up type model.

A comparison of the top-down type economic models showed that the carbon tax rates estimated to be necessary to stabilize CO_2 emissions at 1990 levels range from 9,000 yen to 35,000 yen/tC. The macro-economic losses caused by these taxes range between 0.04% and 5% of GDP. The GDP growth rate is reduced by between 0.01% and 0.5%.

A high GDP growth rate requires a high carbon tax rate to stabilize CO_2 emissions which increases the loss of GDP. The recycling of carbon tax revenue softens the impact on the macro-economy.

The only bottom-up type economic model estimates a much lower carbon tax. It estimates that 3,000 yen/tC could stabilize Japan's CO_2 emissions, if the tax revenue was reinvested as a subsidy for the optimum introduction of energy conservation technology. In this case, the direct cost of such a carbon tax (estimated multiplying the CO_2 emission by the carbon tax rate) would be 0.17% of GDP in the year 2000.

World economic models were also reviewed. It was found that the economic loss caused by the introduction of a carbon tax was lower than those estimated by Japanese models, even though there was a wide range of values. This wide range was caused by differences in model structures, input assumptions and policy assumptions, such as recycling of tax revenue, and international adjustment policies, such as tradable permits.

The results of this review were reflected in the design of the group's models.

5. Development of World Economic Models

Five world economic models were developed: a medium-term econometric model; two dynamic optimization models; a system dynamics model; and, a two country model.

The medium term econometric model is comprised of 29 countries and 7 regions. Developed country models - a Keynesian type and a "demand-pull" type - and Developing country models - a "supply-pull" type model with demand-supply adjustment - are linked through four kinds of trade matrices. To analyze the relationship between global environmental problems and economic growth, the environmental pollution sector was linked to an industrial production model, and an energy consumption model.

Several simulations using this model showed that the existence of north-south differences would increase the gap between their respective energy efficiencies, CO_2 reduction rates and GDP losses caused by CO_2 emission reductions. Thus, it was suggested that there is a need for developing countries to receive ODA from developed countries.

A long term dynamic optimization model was developed by improving the GLOBAL 2100

model to estimate the economic loss and secondary benefits caused by CO_2 reduction policies in the Asian-Pacific region. This is an 8 region model. Table 1 shows economic losses from CO_2 reductions and economic gains from reductions in NO_2 and SO_2. Carbon emission stabilization policies would cause considerable economic losses in DAE (Dynamic Asian Economy) countries. However, these policies would cause very small losses in Japan and India, but secondary benefits from these policies would exceed economic losses here. This suggests that carbon emission stabilization policies have economic advantages for some countries, even when the global warming issue is not considered.

The other types of dynamic optimization models were developed by improving and integrating the DICE model and the GLOBAL 2100 model in order to find the optimal path for economic growth taking into account the cost and benefit (damage) of global warming abatement policies.

The simulation results of this model show the social costs of carbon emissions depend on the discount rate, climatic sensitivity and the shape of the damage function.

The system dynamics model was also developed by improving WORLD 3 to analyze the long-term economic benefit of investment in environmental protection. Two new modules were added to WORLD 3 - a pollution abatement investment module to estimate the stabilization effects of this investment on labor supply and a resource conservation investment module to evaluate its effects on reducing resource extraction costs.

The simulation results of this model showed that no investment leads to a decline in economic production until the year 2040, but investing 15% of industrial capital in environmental protection would lead to sustainable economic activity until the end of the next century. This suggests that investment in environmental conservation is necessary to protect the foundations of the world's long-term economic activity.

The two-country model was also developed to analyze the interaction between Japan and China if a carbon tax was introduced. The result of this model's simulation showed that an annual 2% increase in energy prices in Japan and a 4% increase in China are necessary to stabilize their respective CO_2 emissions. The most efficient policy to reduce both countries' emissions is to transfer a part of Japanese carbon tax revenue to China for the construction of oil natural gas pipeline network.

Table 1 Secondary benefits from carbon emission stabilization (per cent)

	Japan				China			
	Gains from				Gains from			
	SO_2 Cut	NO_x Cut	Total	CO_2 Cut	SO_2 Cut	NO_x Cut	Total	CO_2 Cut
2000	0.006	0.079	0.220	-0.148	0.010	0.135	0.378	-0.938
2010	0.008	0.114	0.319	-0.200	0.017	0.227	0.633	-2.095
	India				DAE			
	Gains from				Gains from			
	SO_2 Cut	NO_x Cut	Total	CO_2 Cut	SO_2 Cut	NO_x Cut	Total	CO_2 Cut
2000	0.010	0.134	0.373	-0.074	0.047	0.637	1.780	-5.622
2010	0.011	0.154	0.429	-0.389	0.073	0.992	2.769	-9.518

6. The Development of the Domestic Economic Models

To analyze the more detailed relationships between global environmental policy and economic growth in Japan, two long-term models were developed, i.e. a general equilibrium model, and a dynamic optimization model.

The general equilibrium model was developed as a Japanese version of the Second Generation Model being developed by the Pacific North West Laboratory. This model is comprised of three production sectors, a household sector and a government sector. The energy production sector is divided into a further 8 sectors, in order to precisely estimate emission of green house gases.

Figure 2 shows the carbon tax rate, and reductions in CO_2 and GDP in case of tax revenue recycled to consumers estimated using this model if carbon emissions were stabilized at the 1990 level from the year 2000. A tax rate of Y24,600/tC would be required to stabilize CO_2 emissions at the year 2000 while the real GDP would decline by only 0.42%. As the estimation did not consider the introduction of new technologies such as solar energy, the actual tax rate and GDP loss would be less than estimated.

The other long-term prediction model is a dynamic optimization model called GDMEEM. This model is comprised of energy production and energy consumption sectors, and these sectors are adjusted by the market mechanism. The energy consumption sector is divided into 16 sectors including industrial, agriculture, transport, service and residential sectors. This model's simulations show the macro-economic loss of stabilizing CO_2 emissions is very small, i.e. about 0.1%. However, some industrial sectors (steel, ceramics, chemicals and paper) suffer considerable losses, as shown in Figure 3. This simulation indicates there are trade-offs between economic efficiency and the balance in burden sharing, and also indicates there are good effects from subsidies, including the recycling of tax revenue.

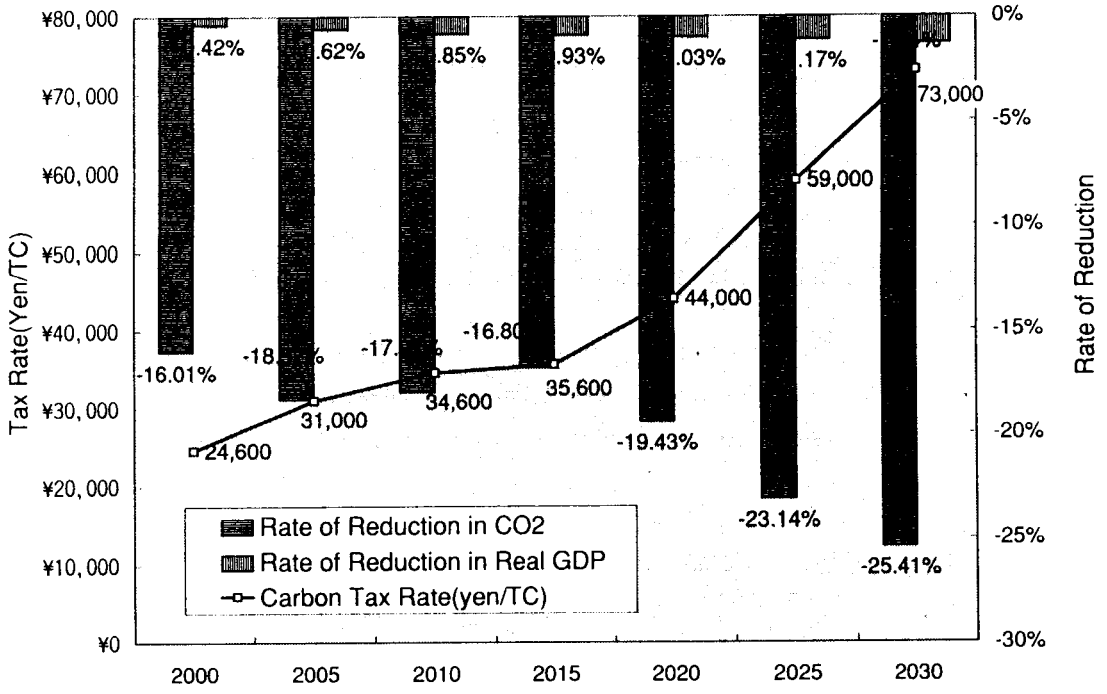

Figure 2. Rate of carbon tax and reduction in CO_2 & real GDP

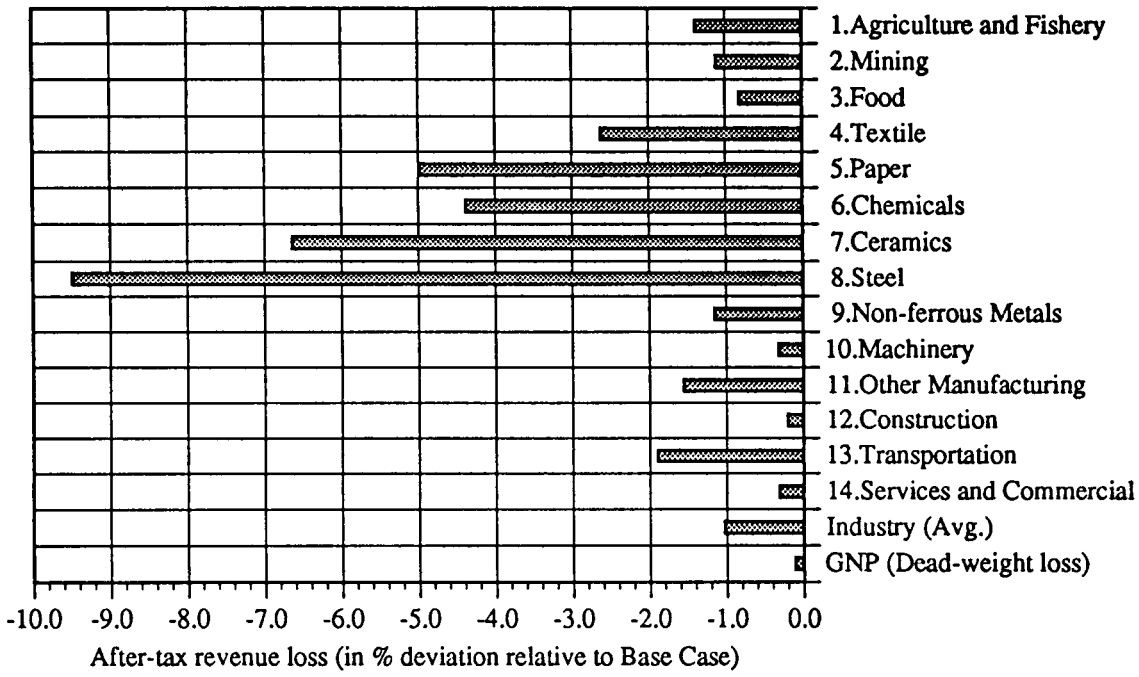

Figure 3. Sectoral after-tax revenue losses incurred by carbon taxation

7. A questionnaire survey of current HDP activities

A questionnaire survey was conducted on about 100 researchers in the field of human dimension studies of global environmental change to identify the current situation and future activities in relation to HDP. The results show that the field will receive the greatest amount of research interest in Japan in the future is the impact of global environmental change, stock analysis of environmental assets, environmental ethics and environmental education, plus integrated assessment modelling.

8. Concluding Remarks

The 5-year research program produced major components for economic models, and several components for environmental models to link these economic models. The program also conducted simulation analyses using these models and showed that some trade-offs between economic growth and environmental conservation will occur. Some of these results have already been input into the political decision making process and contributed to supplying information. However, these models will be upgraded and integrated so as to find the conditions for sustainable development. To reach this objective, a new research project will be initiated to develop a more sophisticated and operational models that can be used to find global solutions to environmental problems.

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