Assessment of CO_2 Reductions and Economic Impacts Considering Energy-Saving Investments

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Abstract

Using a global dynamic optimization model that includes a notion of endogenous energy-saving investments, economic impacts and energy-system changes were assessed under several policy cases where CO_2 concentration is stabilized at the 450, 500, and 550 ppm levels by the year 2100. The relationships between investments in energy-saving technologies and improvements in energy efficiency were exogenously formulated from the results of the AIM/Enduse model applied to Japan, and these expressions were endogenously included in the global dynamic optimization model.

When practical energy-saving technologies are taken into consideration, these options have the potential to decrease the GDP loss during the 21st century from 2.5% to 2.1% in the 450 ppm case. In the 550 ppm case, however, the differences between results with and without energy-saving investments are small, because a shift to low-carbon-intensive energies such as gas and renewable energies does not occur to a significant extent under this target.

1. Introduction

In general, there are various options to reduce energy-related CO_2 emissions. One important measure for reducing CO_2 emissions is the dissemination of energy saving technology. In particular, investment in energy-saving technologies in the manufacturing sector can be considered one of the predominant measures to reduce energy demands. To assess the effects of energy saving, however, it is necessary to determine the relational expressions between investments in energy-saving technologies and improvements in energy efficiency. These relationships make it possible to analyze the effects of energy saving for the reduction of CO_2 emissions.

When evaluating factors contributing to the reduction of CO_2 emissions, CO_2 emissions are often decomposed using a simple hypothetical identity called the Kaya identity [Yamaji et al., 1991]. However, CO_2 absorption measures such as CO_2 capture and storage have been in focus in recent years, and this simple Kaya identity is therefore sometimes described in greater detail in the latest studies. For example, Kawase et al. [Kawase et al., 2005] separate CO_2 emissions into five factors: i) the ratio of net CO_2 emissions including CO_2 capture and storage to generated CO_2 emissions, ii) carbon intensity (i.e., the ratio of generated CO_2 emissions to primary energy consumption), iii) the inverse of energy conversion efficiency (i.e., the ratio of primary energy consumption to final energy consumption), iv) the aggregated energy intensity (i.e., the ratio of final energy consumption to economic activity), and v) economic activity. Therefore, the extended Kaya identity in this study becomes as follows:

$$C = \frac{C}{C_s} \cdot \frac{C_s}{Ep} \cdot \frac{Ep}{Ef} \cdot \frac{Ef}{A} \cdot A = s \cdot i \cdot e_p \cdot e_f \cdot A$$

where C is total CO_2 emissions including CCS, Cs is fossil and industrial CO_2 emissions, Ep and Ef are primary and final energy consumption respectively, A is Economic activity, s is the ratio of net CO_2 emissions to fossil & industrial CO_2 emissions, i is Carbon intensity, e_p is the inverse of energy conversion efficiency, and e_f is the aggregated energy intensity.

The first term reflects the effects of artificial absorption measures such as CO_2 capture and storage of generated CO_2 emissions. The second term represents the effects of shifting from carbon-intensive fuels to lower carbon energies. In the third term, the effects of measures for efficiency improvement in the transformation from primary energy to final energy are expressed. The fourth term describes the effects of energy efficiency improvements at the end-use points. Therefore, measures for investments in energy saving in end-use technologies, which are the main focus of attention in this study, are reflected in the fourth term.

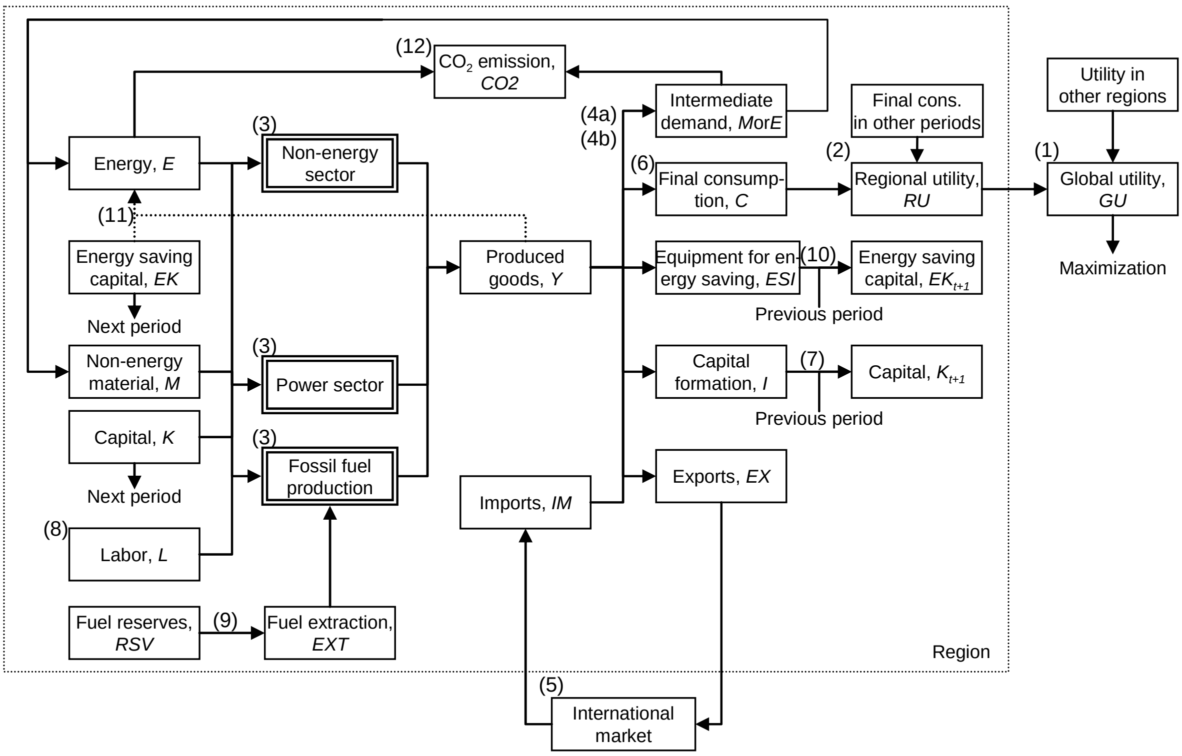
In order to suggest efficient policies for CO_2 reduction, it is necessary to estimate the most suitable combinations among the contributing factors described above, and it is also important to analyze the timing of the implementation of appropriate measures. To solve these issues, it is often useful to use integrated models and linkages between top-down and bottom-up models. For example, in the first version of MERGE [Manne et al., 1995], there is a linkage from ETA-MACRO to the CLIMATE and IMPACT submodels, where MERGE is an integrated assessment in which the costs of abatement are explicitly balanced off against the benefits of reducing the impacts of climate change. The present study mainly uses a top-down model that is also linked with a bottom-up model in order to assess CO_2 reductions and economic impacts by considering energy-saving investments. For another example, The National Institute for Environmental Studies and Kyoto University have evaluated price and economic impacts of a carbon tax in Japan [Kainuma et al, 2004], by interlinking three different models: the AIM/Material model [Masui, 2005] which is a country-based computable general equilibrium model with recursive dynamics and deals with not only monetary balances but also material balances, the AIM/Enduse model [Kainuma et al., 2002] which is a country-based bottom-up optimization model with a detailed technology selection framework, and the AIM/Top-down model [Kainuma et al., 2002] which is a global computable general equilibrium model with recursive dynamics.

For the purpose of estimating effectiveness of energy-saving investments endogenously from a long-term perspective, the same methodology of linking the AIM models mentioned above was adopted, but a different type of a global model was introduced in this study. The reason is that investments in the recursive dynamic model mentioned above is given exogenously year by year by using appropriate investment functions. However, the main discussion in this study is to focus on the ways of energy-saving investments endogenously under various scenarios. From these viewpoints, it is more appropriate to use a dynamic type model from a long-term perspective, so that the global dynamic optimization model with multi-regions and multi-sectors named AIM/Dynamic-Global was developed, and the AIM/Dynamic-Global model is soft-linked with the AIM/Enduse model in order to depict the reality of technological development. This global dynamic optimization model can simulate fuel selections among fossil energies such as coal, oil, gas, and renewable energies in order to assess the relationships between CO_2 generation and primary energy supply. Moreover, endogenous energy-saving investments and their effects are also set in the model to assess the relationships between energy demands and economic activities. With regard to the relationships between investments in energy saving and improvements in energy efficiency, the relational expressions are determined by the AIM/Enduse[Japan] model, which is a bottom-up optimization model in Japan. This bottom-up model provides an extensive database of existing and improved technology options and the results of bottom-up analysis are applied as an input to the AIM/Dynamic-Global model in this study.

The objective of this study is to evaluate the effects of energy-saving technological changes for the reduction of CO_2 emissions, by using both the AIM/Enduse model and the AIM/Dynamic-Global model. In particular, this paper focuses on the consequences of endogenous technological changes in terms of the relationships between investments in energy-saving technologies and improvements in energy efficiency.

2. Model structure

The model used for this analysis is a global dynamic optimization model with multiple regions and economic activities. Moreover, this model can introduce endogenous energy-saving investments and estimate their effectiveness. Figure 1 shows the overall structure of the model.



The numbers (1) - (12) correspond to the equation numbers shown below.

Characters in *italics* represent the variables in the equations.

Figure 1 Structure of the AIM/Dynamic-Global model

In order to maximize the global utility (GU), the economic activities are calculated. The following are the main equations in this model:

(1) $GU = \sum_r wgt_r * RU_r$

(2) $RU_r = \sum_t udf_{t,r} * u_r\left(C_{t,r,ne}, pop_{t,r}\right)$

(3) $Y_{t,r,i} = f_{t,r,i}\left(K_{t,r,i}, L_{t,r,i}, M_{t,r,j,i}, (aeei_{t,r,i,e} * AE_{t,r,i,e}) * E_{t,r,e,i}, \sum_{grd} EXT_{t,r,ff\in i,grd}\right)$

(4a) $Y_{t,r,ne} + IM_{t,r,ne} = \sum_j M_{t,r,ne,j} + C_{t,r,ne} + \sum_j I_{t,r,ne,j} + ESI_{t,r,mnf\in ne} + EX_{t,r,ne}$

(4b) $Y_{t,r,e} + IM_{t,r,e} = \sum_j E_{t,r,e,j} + C_{t,r,e} + EX_{t,r,e}$

(5) $\sum_r IM_{t,r,i} = \sum_r EX_{t,r,i}$

(6) $C_{t,r,e} = c_{t,r}\left(\sum_{ne} C_{t,r,ne}\right)$

(7) $K_{t+1,r,i} = (1-dep)^{ts_t} * K_{t+1,r,i} + ts_t * 0.5 * \sum_{ne}\left(I_{t,r,ne,j} + I_{t+1,r,ne,j}\right)$

(8) $\sum_i L_{t,r,i} \le lab_{t,r}$

(9) $RSV_{t+1,r,ff,grd} = RSV_{t,r,ff,grd} - ts_t * 0.5 * \left(EXT_{t,r,ff,grd} + EXT_{t+1,r,ff,grd}\right)$

(10) $EK_{t+1,r,mnf} = (1-dep)^{ts_t} * EK_{t+1,r,mnf} + ts_t * 0.5 * \left(ESI_{t,r,mnf} + ESI_{t+1,r,mnf}\right)$

(11) $AE_{t,r,mnf\in i,e} = g_{r,e}\left(\dfrac{EK_{t,r}}{Y_{t,r,mnf\in i}}\right)$

(12) $CO2_t = \sum_r \sum_e cef_e * \left(\sum_j E_{t,r,e,j} + C_{t,r,e}\right) + othco2_t$

Sets:

t: time period, r: region, i and j: sector and commodity, e∈i: energy (subset of sector, i),
ne∈i: non-energy (subset of sector, i), ff∈e: fossil fuels (subset of energy, e),
mnf∈ne: manufacturing sector (subset of non-energy, ne), grd: grade of fossil fuels.

Exogenous parameters:

wgt_r: regional weight, $udf_{t,r}$: utility discount factor, $pop_{t,r}$: population,
$aeei_{t,r,i,e}$: autonomous energy efficiency improvement, $lab_{t,r}$: labor supply limit,
dep: depreciation rate, ts_t: time step, cef_e: carbon emission factor,
$othco2_t$: CO_2 emissions from other sources.

Endogenous variables:

GU: global utility, RU_r: regional utility, $Y_{t,r,i}$: production, $C_{t,r,i}$: final consumption,
$K_{t,r,i}$: capital stock, $L_{t,r,i}$: labor input, $M_{t,r,j,i}$: non-energy intermediate demand,
$E_{t,r,e,i}$: energy input, $AE_{t,r,i,e}$: additional energy efficiency improvement,
$EXT_{t,r,ff,grd}$: extracted fuel resources, $IM_{t,r,i}$: imports, $I_{t,r,i,j}$: fixed capital formation,
$ESI_{t,r,mnf}$: capital formation for energy saving (i.e. energy-saving investments),
$EX_{t,r,i}$: exports, $RSV_{t,r,ff,grd}$: fuel reserves,

$EK_{t,r}$: energy-saving capital stock, $CO2_t$; global CO_2 emissions.

2.1 Time period, region and activity

The model has a dynamic optimization framework maximizing GU, the global discounted utility from the final consumption over the entire time period. The regional utilities calculated from Equation (2) are aggregated based on the Negishi weight (wgt_r) [Negishi, 1960; Mori, 1996] in Equation (1). The base year and final year are set as 1995 and 2100, respectively, and the time steps are at intervals of 5 years until 2000 and 10 years from 2000 onwards. The classifications of regions and economic activities are shown in Table 1 and Table 2, respectively. The GTAP data and IEA energy balance table are used for calibration to reproduce the activities in the initial year.

Table 1 Classification of regions

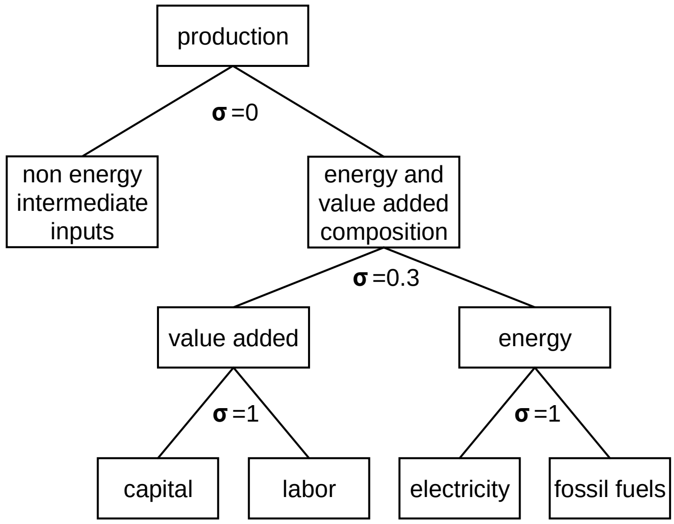
Model regions		Group
JPN	Japan	Annex I
USA	USA	
OECD	Other OECD countries	
FSU	Former Soviet Union	
CHN	China	Non-Annex I
ROW	Rest of the world	

Table 2 Classification of economic activities

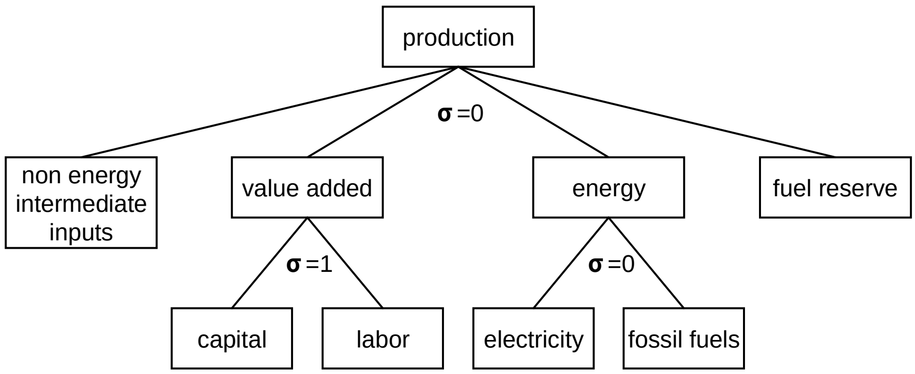
Sectors		Products
Manufacturing	Manufacturing sector	Goods
Services and others	Service, agriculture, construction sectors	Services
Crude oil	Crude oil extraction	Crude oil
Oil products	Oil refinery sector	Oil products
Coal	Coal mining and products	Coal
Gas	Gas mining and products	Gas
Thermal power	Thermal power sector	Electricity
High-cost non-thermal power	Non-thermal power with high cost	
Low-cost non-thermal power	Non-thermal power with low cost	

2.2 Production function

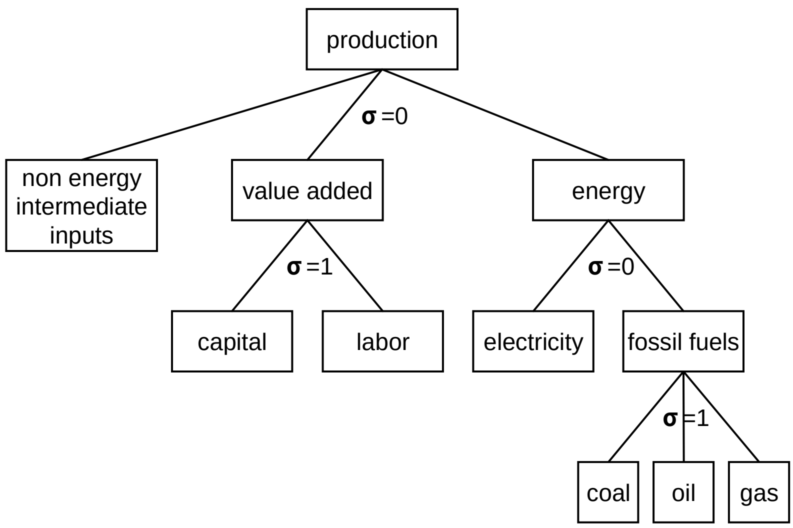
Equation (3) represents the production function. Capital, labor, energy, and non-energy intermediate goods are the inputs for production. For the extraction of fossil fuels, the amount of fuel deposits is also taken into account and energy types are classified into coal, oil, gas, and electricity. Each sector produces a specific commodity, as shown in Table 2. Figure 2 shows the production structure in detail and the following paragraphs in this subsection explain the formulation of each production function.



a. Production structure in non-energy sector



b. Production structure in fossil fuel production sector



c. Production structure in electricity production sectors

Figure 2 Structures of production activity

a. Non-energy sector

The elasticity of substitution between non-energy intermediate inputs and combinations of energy and value added is assumed to be 0. In other words, the Leontief production function is assumed. The elasticity of substitution between energy and value added is assumed to be 0.3. The elasticity of substitution between capital and labor, and that between electricity and fossil fuels, are both assumed to be 1.

b. Fossil fuel production sector

In the fossil fuel mining sector, i.e., crude oil, coal, and gas, the elasticity of substitution between value added and energy is assumed to be 0. Moreover, the reserves of fossil fuels are assumed to deplete in proportion to the amount of extraction. The extraction costs in each grade and the quantities of fuel reserves are defined based on Rogner [Rogner, 1997]. It is assumed that the combination of reserves at the lowest cost supplies fuels in the initial year and the upper limits of recoverable reserves are introduced on fuel extraction by each grade. If fuel demand exceeds the upper boundary of the reserves at the lowest cost, then the reserves at the higher cost supply fuel to meet the demand. The elasticity of substitution among energy types is assumed to be 0 in the fossil fuel production sector. Since the production of oil products involves only the refining of crude oil, it does not need fuel reserves. The produced fossil fuels are consumed directly or converted into electricity.

c. Power sectors

The power sectors are classified into the thermal power sector and other power sectors for this analysis. The elasticity of substitution between value added and energy is assumed to be 0, as in the case of the fossil fuel production sector. In the thermal power sector, coal, oil, and gas are treated as inputs, and electricity is calculated as an output. The fossil fuel inputs are aggregated using the Cobb-Douglas function. On the other hand, the non-thermal power sector can supply electricity without fossil fuel inputs. Two types of non-thermal power sectors are represented in this model: those with high-cost and low-cost plants, respectively. It is assumed that there is an upper boundary on the amount of electricity produced by the low-cost type while there is no upper limit on the electricity supply from the high-cost type.

2.3 Supply and demand of commodities

Produced commodities and imported commodities are distributed into intermediate demands, final consumptions, investments (fixed capital formation), capital formation for energy-saving investments (only manufactured goods), and exports, as shown in Equations (4a) and (4b). Equations (4a) and (4b) represent the non-energy goods and energy goods markets, respectively. Upper boundaries are introduced on the ratio of imports to domestic products for non-energy goods; however, upper boundaries on the import share of energy goods are not determined. In the international market, the total imports are equal to the total exports in each commodity, as shown in Equation (5).

2.4 Household final consumption

In this study, the household sector in each region is assumed to consume non-energy goods based on the Cobb-Douglas function in each period. The total present value of final demands is defined as the regional utility. On the other hand, since household energy demands are assumed to be derived demands, energy demands in the household sector are calculated from the total of non-energy final consumption goods, as shown in Equation (6). The elasticity of substitution among energy types is assumed to be 1.

2.5 Investment and capital stock

The total income in the household sector is used as final demand expenditure to increase the present utility or savings to increase the future utility, and the investment is implemented for future's activity. The share of the fixed capital formation of each investment good is assumed to be fixed. The investment goods are distributed to each sector and accumulated as capital stock, as shown in Equation (7). The putty-clay relationship is assumed to represent the process of investment and capital stock. That is to say, investment goods can be accumulated in any sector, but they cannot be moved among the sectors after accumulation. Incidentally, labor can freely move among the sectors in each region. These relationships are explained by Equation (8).

2.6 Energy-saving investments and features of endogenous technology change

As one of the options to mitigate CO_2 emissions, energy-saving investments to reduce energy demands are considered in this model. Generally, the price of equipment with high energy efficiency is higher than that of ordinary equipment. In this model, the difference between these prices is regarded as an additional energy-saving investment. The relationships among an additional energy-saving investment, accumulated energy-saving capital stock and additional energy efficiency improvement are introduced as endogenous technology change in this model. The relationships between the difference in costs and the effect on energy saving are introduced from the results of the AIM/Enduse model applied to Japan. Figure 3 shows the results of the AIM/Enduse model in the manufacturing sector. As shown in this figure, the accumulated energy-saving capital stock per output determines the additional energy efficiency improvement in the manufacturing sector. This relationship is introduced in the global dynamic optimization model as Equation (11). That is to say, the soft-linkage between this dynamic optimization model and the AIM/Enduse model is adopted in this study. Equation (10) shows the process of capital stock formation for energy saving. The energy-saving investment, ESI, and as a result, the additional energy efficiency improvement, AE, is determined endogenously. If the marginal CO_2 reduction cost exceeds the cost of an energy-saving investment, then this investment will be implemented in this model. Therefore, in this paper, this additional energy efficiency improvement under the CO_2 emission constraint is regarded as induced technology change (ITC).

In this model, energy-saving investments can be introduced only in the manufacturing sector. Energy-saving investments in other sectors such as the energy production sector and the residential sector are not considered, because the energy demand systems in the manufacturing sector and the other sectors are different and it would not be appropriate to apply the relational expressions in the manufacturing sector directly to other sectors. Moreover, the AIM/Enduse model can only deal with practical and existing technologies at present, so that relational expressions between energy-saving investments and their effectiveness in the manufacturing sector simulated by the AIM/Enduse model are available only up to 2030. Therefore, with regard to the situation after 2030, it is assumed in this study that the same relational expressions between these investments and their effectiveness will continue until the end of the 21st century under the assumption of the least expected technology innovation.

In addition, for regions other than Japan there is no similar result because of the lack of available data for the model in other countries. Consequently, in this analysis the relational expressions between these investments and their effectiveness in Japan are applied to other regions as well, under the assumption that energy demand systems do not change drastically among these regions compared to Japan. In general, however, the improvement in energy efficiency in Japan has already reached the world's highest level. The results of this simulation thus show conservative values for the effects of energy-saving improvements in the world, because greater improvements in energy efficiency can be expected to take place in regions other than Japan, and especially in developing countries.

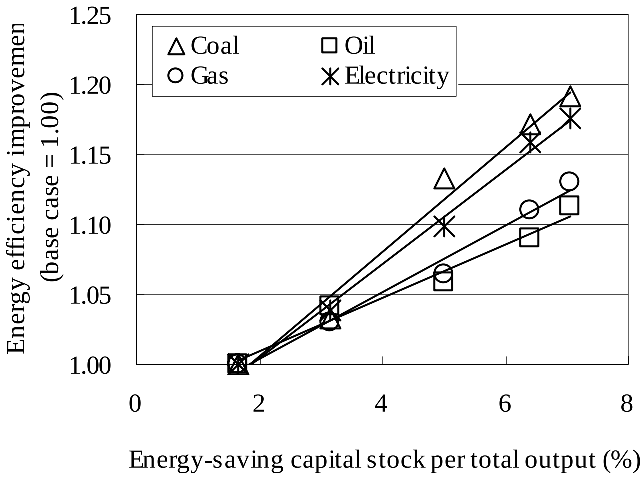


Figure 3 Relationships between energy-saving investments and energy efficiency improvements

2.7 CO_2 emissions

Equation (12) represents the calculation of CO_2 emissions in this model. CO_2 emissions from the combustion of fossil fuels are endogenous variables. Other emission sources such as land use and industrial processes are regarded as exogenous parameters. In the simulation, CO_2 emissions from these other sources are fixed during the simulated period and aggregated exogenously into global emissions.

When the CO_2 emissions constraint is introduced in order to stabilize the atmospheric CO_2 concentration, only the global emission constraint is specified in this model. The distribution of CO_2 emissions among regions is calculated endogenously based on the criterion of equal marginal reduction cost.

3. Simulation results

The following scenarios are prepared for analyzing the effectiveness of energy-saving investments;

1) Reference case: No constraint on CO_2 emissions and no energy-saving investment.
2) Reference case with energy-saving investments: No CO_2 constraint but introduction of energy-saving investments.
3) CO_2 stabilization case without energy-saving investments: introduction of CO_2 constraint to stabilize CO_2 emissions at the 450, 500 or 550 ppm levels without energy-saving investments.
4) CO_2 stabilization case with energy-saving investments: introduction of CO_2 constraint to stabilize CO_2 emissions at the 450, 500 or 550 ppm levels with energy-saving investments.

In the “reference case”, endogenous technology change is not taken into account. If the energy-saving investments are cheaper options compared to the increase of prices due to depletion of fossil fuel resources, energy-saving investments will be selected in the scenario of “Reference case with energy-saving investments.” In the case of “CO_2 stabilization case without energy-saving investments,” a fuel transition will be the major countermeasure to reduce CO_2 emissions. On the other hand, in the case of “CO_2 stabilization case with energy-saving investments,” the more efficient technologies will be induced endogenously to reduce CO_2 emissions. The feature of this additional energy efficiency improvement under the CO_2 emission constraint is regarded as ITC.

The parameters such as autonomous energy efficiency improvements are calibrated to reproduce the CO_2 emissions and GDP proposed by the International Model Comparison Project (IMCP) for the reference case, and CO_2 emissions from land use and industrial processes in the initial year are reconciled with the proposed CO_2 emissions. Figure 4 shows the main simulation results of the reference scenario and the trajectories proposed by the IMCP. Here, the area charts represent the results for the Annex I and Non-Annex I groups in the reference case in this simulation, and the trajectories of emission results under various climate policy targets are also described by line charts in the figure showing CO_2 emissions.

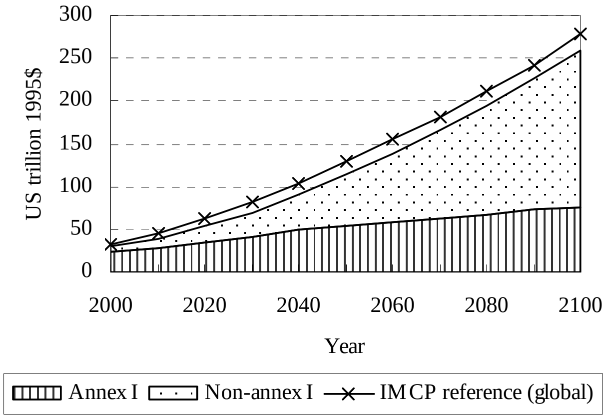


Figure 4-(a) GDP

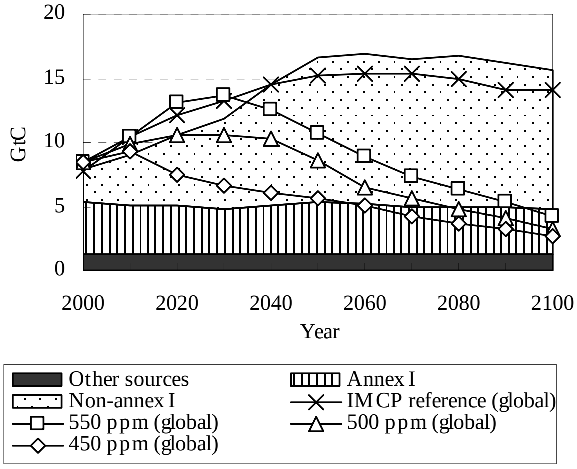


Figure 4-(b) CO_2 emissions

Figure 4 Results of simulations of the reference scenario (area charts) and trajectories proposed by the IMCP (line charts)

The simulations in this study took three CO_2 concentration stabilization policy cases into account, in which CO_2 concentration is stabilized at the 450, 500, and 550 ppm levels by the year 2100. Since this model does not include a module for calculating CO_2 concentration, the global CO_2 emissions scenarios prepared by the IMCP were introduced exogenously. For CO_2 reduction simulations, two scenarios—with and without energy-saving investments—were considered in this study.

(1) Cases without energy-saving investments

Figures 5 and 6 show the GDP changes and the marginal cost of CO_2 reductions, respectively. In the 450 ppm scenario, the total GDP during the 21st century, under a 5% annual discounted rate, is reduced by 2.46% compared to the reference scenario. The marginal cost of CO_2 reductions in 2100 is 1700 US$/tC. On the other hand, the discounted GDP loss in the 550 ppm stabilization scenario is 0.85% compared to the reference scenario and the marginal cost of CO_2 reduction in 2100 is 76 US$/tC. Fossil fuel supply decreases under the high CO_2 constraint, as shown in Figure 7. These results indicate that, by a moderate level of fossil fuel reductions, it will be possible to achieve the mild constraint of a CO_2 reduction scenario such as the 550 ppm stabilization scenario. However, the 450 ppm scenario needs a drastic fuel transition and, as a result, it is vulnerable to severe economic damage.

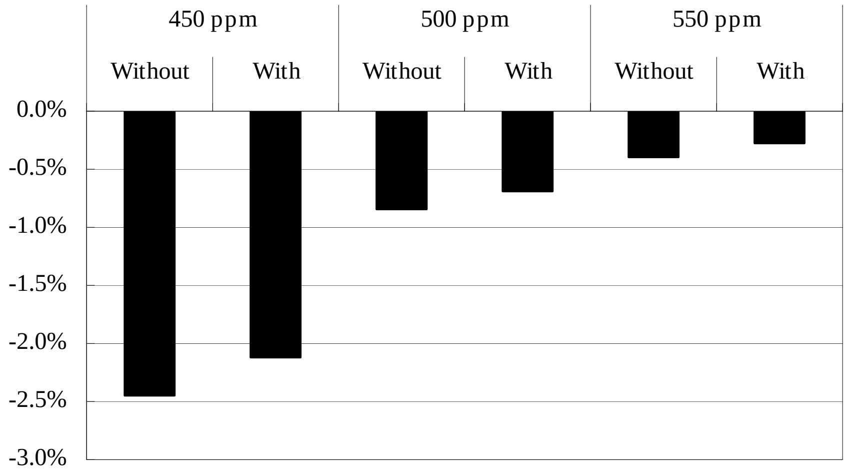


Figure 5 GDP changes during the 21st century compared to the reference case (discount rate: 5%/year)

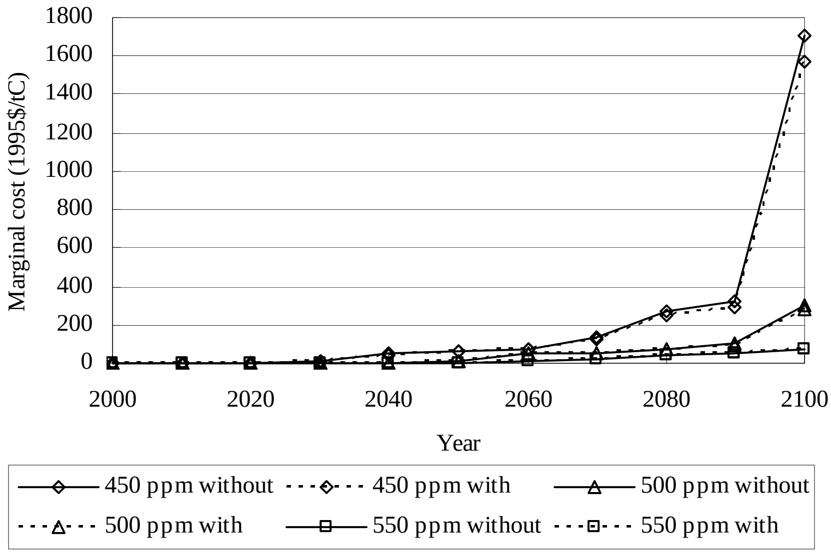


Figure 6 Changes in marginal cost of reducing CO_2 emissions

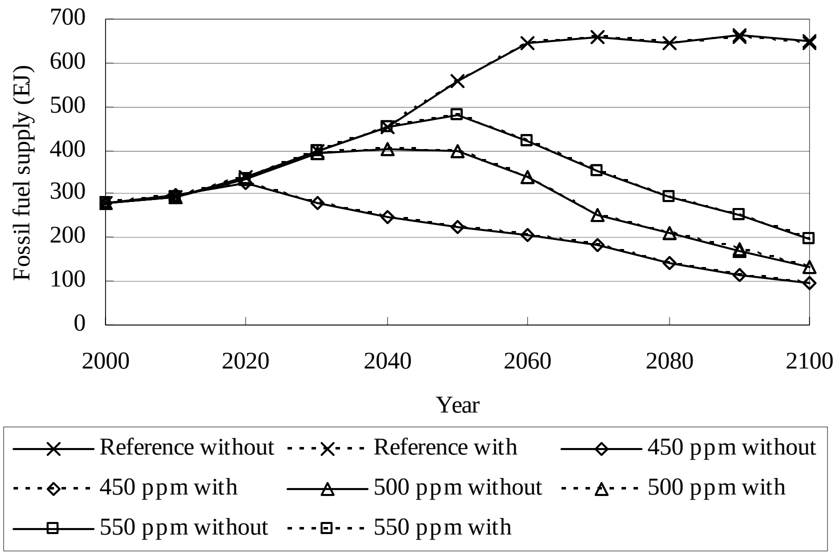


Figure 7 Changes in fossil fuel supply

(2) Cases with energy-saving investments

Since energy-saving investments in this simulation are limited only to the manufacturing sector, the effectiveness of the endogenous framework of energy-saving investments does not seem to be significant. In the 450 ppm stabilization scenario with energy-saving investments, energy-saving investments will be implemented from 2010 onward. Compared to the case in the same scenario without endogenous energy-saving investments, the share of energy-saving investments to GDP in the world will range from 0.2 to 1.0%. In this case, the production of manufacturing will increase by 0.017% to 2.3% by introducing energy-saving investments. Moreover, these manufacturing production activities will induce service demands by 0.086% to 0.49%. As a result, this simulation shows that existing advanced technologies still have the potential to decrease the GDP loss from 2.5% to 2.1% under the cases without and with energy-saving investments, respectively, to stabilize CO_2 concentration at the 450 ppm level. The marginal cost of CO_2 reductions in the case with energy-saving investments will change by -6.3% to -11% compared to the case without energy-saving investments after 2040, where the differences between results of marginal costs with and without energy-saving investments are from 4 to 135 $/t-C. These results indicate that energy-saving investments will be regarded as cheaper options. In addition, the demand created by energy-saving investments will also contribute to decrease the GDP loss due to its income effect.

On the other hand, the effectiveness of energy-saving investments in the 550 ppm stabilization scenario is very small, because a shift to low-carbon-intensive energies such as gas and renewable energies does not occur to a significant extent under this target. Therefore, a fuel transition is the foremost option to reduce CO_2 emissions, and energy-saving investments seem to be more appropriate for introduction under the more severe CO_2 reduction policy.

Figure 8 shows the GDP changes when different levels of energy efficiency improvements are assumed in a sensitivity analysis, under the 450 ppm scenario with energy-saving investments.

Even though the effects of the additional energy efficiency improvement becomes more improved by 10%, 20% and 30%, respectively compared to the base case shown in Figure 3, the results only show a few impacts of mitigating the GDP loss. On the other hand, even if the upper bound of the additional energy efficiency improvement is expanded by 10% compared to the base case shown in Figure 3, it shows hardly any change at all. This is because, as is mentioned in section 2.6, energy-saving investments decribed in equation (11) are introduced only in practical technologies in the manufacturing sector. As a result, even a 30 % additional improvement in energy efficiency in the manufacturing sector will not become a breakthrough to stabilize CO_2 concentration at the 450ppm level. Therefore, in order to reduce the GDP loss further more by introducing energy-saving investments, it is necessary to take into account not only improvements of practical technologies but also the development of the drastic cost-effective technologies.

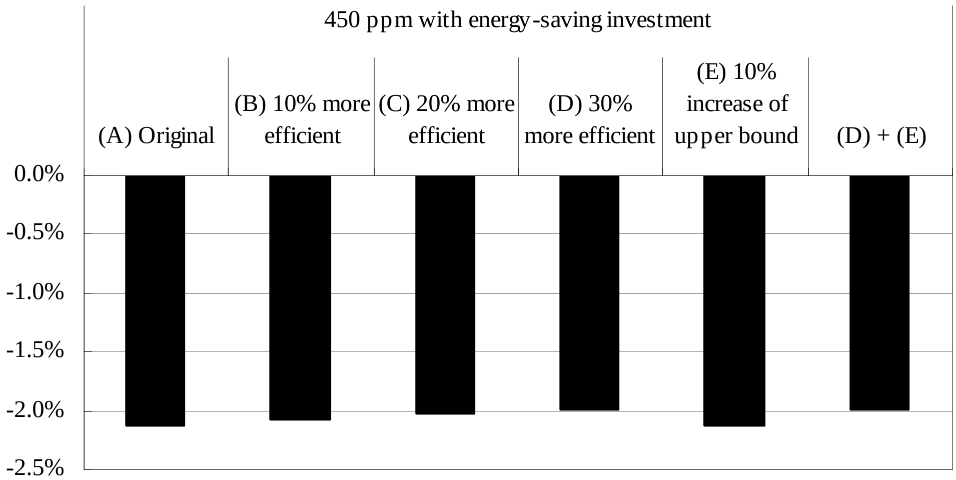


Figure 8 GDP changes compared to the reference case under the assumption of additional energy efficiency improvement (period: during 21st century, discount rate: 5%/year)

4. Conclusion

This model simulation focused on the consequences of endogenous investment in energy-saving technology and evaluated the effects of such investment for reaching different CO_2 reductions targets. This study took only account of investment in energy-saving investments in the manufacturing sector and did not consider those in other sectors such as the energy production sector and the residential sector. In addition, the relational expressions between energy-saving investments and energy efficiency improvements in Japan were applied to other regions in this study, because of the lack of available data for the model in other countries.

Even though the simulations in this study were conducted under such assumptions, it was found that when CO_2 concentration was set at the 450 ppm stabilization level, the discounted total GDP loss in the 21st century compared to that in the reference scenario decreased from 2.46% to 2.12% due to the effects of energy-saving investments. However, in order to reduce the GDP loss further more by improvements in energy-saving technologies in the 450 ppm case, the development of practical technologies is not enough and it is crucial to take into account the development of the drastic cost-effective technologies, too. When the results in the 550 ppm case were compared with and without energy-saving investments, the differences were small because there were relatively small shifts to low-carbon-intensive energies such as gas and renewable energies.

In order to stabilize the global mean temperature increase at 2°C, the National Institute for Environmental Studies and Kyoto University suggest that it is necessary to stabilize total greenhouse gases (GHGs) at around the 475 ppm level, based on the results of the AIM/Impact[Policy] model [Hijioka et al., forthcoming]. In order to achieve this target, the role of energy-saving investments will become quite important to decrease the economic loss.

There are some issues remaining in this study, such as the necessity of a more detailed formulation of energy-saving investments, regional disaggregation, activity disaggregation, and so on. In particular, the reformulation of energy-saving investments by regions and by sectors is necessary for a more comprehensive estimation of the effects of these investments. Moreover, the robustness of these results has to be investigated. For example, uncertainty of the future energy supplies such as fossil fuel reserves and the limit on low-cost non-thermal power plants will have to be analyzed. The assessment of future advanced technologies as well as the existing technologies also needs to be included for long-term climate stabilization scenarios. Lastly, linkages between the climate model and other modules to estimate non-CO_2 GHG emissions are also important. Therefore, considering these remaining issues, a linkage between this model and the AIM/Impact policy model is planned for further studies of climate policies.

References

Kainuma, M., Y. Matsuoka, and T. Morita (2002). *Climate Policy Assessment*, Springer. pp.1-398

Kainuma, M. Y. Matsuoka, T. Masui, and J. Fujino (2004). "*Carbon Reduction Potential and Economic Impacts in Japan: Application of AIM*." International Energy Workshop. http://www.iiasa.ac.at/Research/ECS/IEW2004/docs/2004P_Masui.pdf

Kawase, R., J. Fujino, and Y. Matsuoka (2005). "*Decomposition analysis of CO_2 emission in long-term climate stabilization scenarios*." Energy Policy: in press.

Hijioka, Y., T. Masui, K. Takahashi, Y. Matsuoka, and H. Harasawa. "*Development of a support tool for greenhouse gas emissions control policy to help mitigate the impact of global warming*." Environmental Economics and Policy Studies: accepted.

Manne, A., R. Richels, and R. Mendelson (1995). "*MERGE—A Model for Evaluating Regional and Global Effects of GHG Reduction Policies*." Energy Policy 23 (1): 17-34.

Masui, T. (2005). "*Policy Evaluations under Environmental Constraints Using a Computable General Equilibrium Model*." European Journal of Operational Research 166 (3): 843-855.

Mori, S.(1996). "*MARIA—Multi-regional Approach for Resource and Industry Allocation model—and Its First Simulations*." Amano, A. (ed.), *Global Warming, Carbon Limitation and Economic Development*, Center for Global Environmental Research, National Institute for Environmental Studies, CGER-I019-'96: 85-108.

Negishi, T. (1960). "*Welfare Economics and Existence of an Equilibrium for a Competitive Economy*." Metroeconomica 12: 92-97.

Rogner, H. H. (1997). "*An Assessment Of World Hydrocarbon Resources*." Annual Review of Energy and the Environment 22: 217-262.

Yamaji, K., R. Matsuhashi, Y. Nagata, and Y. Kaya (1991). "*An Integrated System for CO_2/Energy/GNP Analysis: Case Studies on Economic Measures for CO_2 Reduction in Japan*." Workshop on CO_2 Reduction and Removal: Measures for the Next Century, March 19-21, 1991, International Institute for Applied Systems Analysis, Laxenburg, Austria.