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

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*Using a global dynamic optimization model that includes a notion of endogenous energy-saving investments, economic impacts and energy-system changes are assessed under several policy cases where $CO_2$ concentration is stabilized at the 450, 500, and 550 ppm levels by the year 2100. The effect of increased investments in energy-saving technologies on energy efficiency is derived exogenously from results of the AIM/Enduse model applied to Japan, then endogenized in the global dynamic optimization model.*

*We find that with diffusion of energy-saving technologies, GDP loss during the 21st century falls from 2.5% to 2.1% in the 450 ppm case. The impact is small for the 550 ppm case, however, 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

The role of the diffusion of energy saving technology in achieving $CO_2$ emissions reductions is known to be important. In particular, investments in energy-saving technologies in the manufacturing sector can be considered key to driving down energy demand and hence $CO_2$ emissions in the economy. To assess energy saving as one of many options for reducing $CO_2$ emissions, however, it is vital to understand the interaction between investment in energy-saving technologies and improvements in energy efficiency.

When evaluating factors contributing to their reduction, $CO_2$ emissions are often decomposed using a simple hypothetical identity called the Kaya identity (Yamaji et al., 1991). To address the development of literature on $CO_2$ absorption

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measures such as $CO_2$ capture and storage, the Kaya identity has been described in greater detail in recent years. For example, 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. The extended Kaya identity used in this study is defined as follows:

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

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. Measures for investments in energy saving in end-use technologies – the main focus of this study – are thus reflected in the fourth term.

In order to arrive at efficient policies for $CO_2$ reduction, it is necessary to estimate the optimal combinations of the contributing factors described above. The timing of implementation of appropriate measures must also be explored. To obtain solutions for such issues, it is often useful to use integrated models and linkages between top-down and bottom-up models. For example, the first version of MERGE (Manne et al., 1995) – an integrated assessment in which the costs of abatement are explicitly balanced off against the benefits of reducing the impacts of climate change – links ETA-MACRO to the CLIMATE and IMPACT submodels. To give 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: i) the AIM/Material model (Masui, 2005), a country-based computable general equilibrium model with recursive dynamics that deals not only with monetary balances but also material balances; ii) the AIM/Enduse model (Kainuma et al., 2002), a country-based bottom-up optimization model with a detailed technology selection framework and; iii) the AIM/Top-down model (Kainuma et al., 2002), a global computable general equilibrium model with recursive dynamics.

The analysis presented in this paper 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 the purpose of estimating effectiveness of energy-saving investments from a long-term perspective, the same methodology of linking models as used by AIM is adopted here. However, a different type of global model is introduced in this study for the following reason. Investments in the recursive dynamic model mentioned above is given exogenously year by year, by using appropriate investment functions. Yet, the focus here lies with endogenous energy-saving investments under various scenarios. From this viewpoint, it is more appropriate to use a dynamic model with a long-term perspective, hence the global dynamic optimization model – AIM/Dynamic-Global – is developed, with multi-regions and multi-sectors.

The AIM/Dynamic-Global model is soft-linked with the AIM/Enduse model. The former is a global dynamic optimization model that 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 embodied in the model to assess the relationships between energy demand and economic activities. The impact of investments in energy saving technologies on improvements in energy efficiency is derived by the AIM/Enduse [Japan] model – a bottom-up optimization model applied to Japan. This provides an extensive database for existing and improved technology options. Results derived from the bottom-up analysis are then 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 the AIM/Enduse model and the AIM/Dynamic-Global model. In particular, this paper focuses on the consequences of endogenous technological change 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.

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

$$(1)\ GU = \Sigma_r\, wgt_r * RU_r$$

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

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

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

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

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

$$(6)\ C_{t,r,e} = c_{t,r}\,(\Sigma_{ne} C_{t,r,ne})$$

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

$$(8)\ \Sigma_i L_{t,r,i} \leq lab_{t,r}$$

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

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

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

$$(12)\ CO2_t = \Sigma_r \Sigma_e\, cef_e * (\Sigma_j E_{t,r,e,j} + C_{t,r,e}) + othco2_t$$

Sets:

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

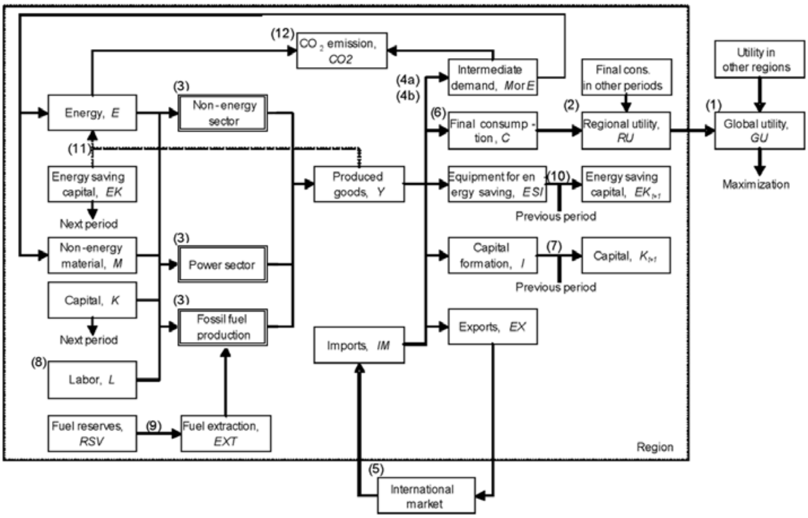
Exogenous parameters:

$wgt_r$: 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, $CO_{2t}$; global $CO_2$ emissions.

**Figure 1. Structure of the AIM/Dynamic-Global Model**




*Note:* The numbers (1) - (12) correspond to the equation numbers shown above. Characters in *italics* represent the variables in the equations.

## 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 and final years are set as 1995 and 2100 respectively. The model is solved in 5-year increments until 2000, and 10-year increments from 2000 onwards. The classifications of regions and economic activities are shown in Table 1 and Table 2 respectively. The GTAP data (McDougall et al., 1998) and IEA energy balance table (IEA, 1998a and 1998b) are calibrated to obtain the activity levels in the initial year.

**Table 1. Classification to 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 | Electricity |
| Low-cost non-thermal power | Non-thermal power with low cost | Electricity |

## 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 with energy types classified into coal, oil, gas, and electricity. Each sector produces a specific commodity, as shown in Table 2. Figure 2 depicts the production structure and the formulation of each production function is explained below.

### *2.2.1 Non-energy sector*

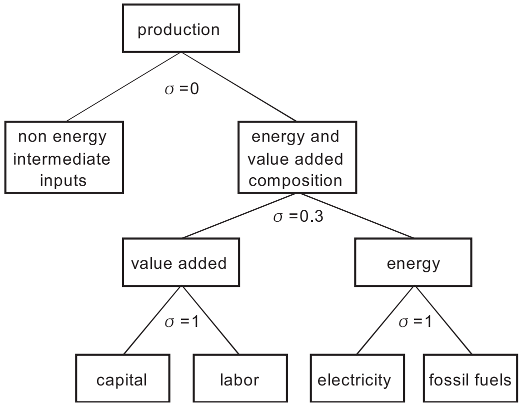
We assume the elasticity of substitution between non-energy intermediate inputs and combinations of energy and value added to be perfectly inelastic. In other words, the Leontief production function is assumed. The elasticity of substitution between energy and value added is assumed to be 0.3. Both the elasticity of substitution between capital and labor, and that between electricity and fossil fuels are assumed unit elastic.

### *2.2.2 Fossil fuel production sector*

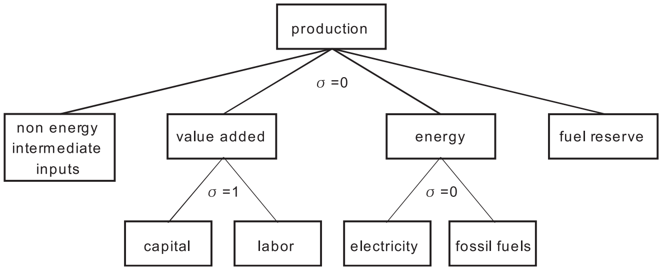
In the fossil fuel mining sector (i.e. crude oil, coal, and gas), the elasticity of substitution between value added and energy is assumed to be zero. Moreover, we assume the reserves of fossil fuels are depleted in proportion to the amount of extraction. The extraction costs in each grade and the quantities of fuel reserves are defined based on Rogner (1997). It is assumed that the combination of reserves that minimizes costs meets demand in the initial year. In addition, upper limits of recoverable reserves are introduced on fuel extraction by each grade. If fuel demand exceeds the upper boundary of the cheaper reserves, then supply taps into the next grade of reserves to meet the demand. Elasticity of substitution among different energy types is assumed to be zero in the fossil fuel production sector. Production of oil products describes the process of refining crude oil, hence no fuel reserves are consumed in production. The produced fossil fuels are either consumed directly or converted into electricity.

**Figure 2. Structures of Production Activity**

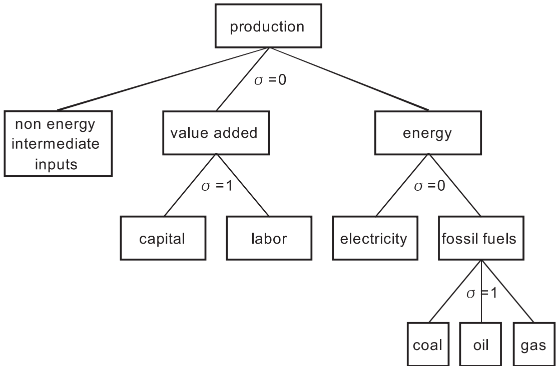
a. Production Structure in Non-energy Sector




b. Production Structure in Fossil Fuel Production Sector




c. Production Structure in Electricity Production Sectors



*2.2.3 Power sectors*

The power sectors are classified into the thermal power sector and other power sectors for this analysis. Like the fossil fuel production sector, we assume perfectly inelastic substitution between value added and energy. 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. The non-thermal power sector can also supply electricity output, but without fossil fuel inputs. This model differentiates the non-thermal power sector into high-cost and low-cost plants. Electricity supply from low-cost plants is subject to an upper limit, whilst no such bounds are set for 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). These equations represent the non-energy and energy goods markets respectively. Upper boundaries are imposed on the ratio of imports to domestic products for non-energy goods; however, no upper limits are set for the import share of energy goods. 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. Here, household energy demands are assumed to be derived demands. Hence total energy demand in this sector is calculated from the total non-energy final consumption goods as shown in Equation (6), assuming elasticity of substitution among energy types takes the value of one.

## 2.5 Investment and Capital Stock

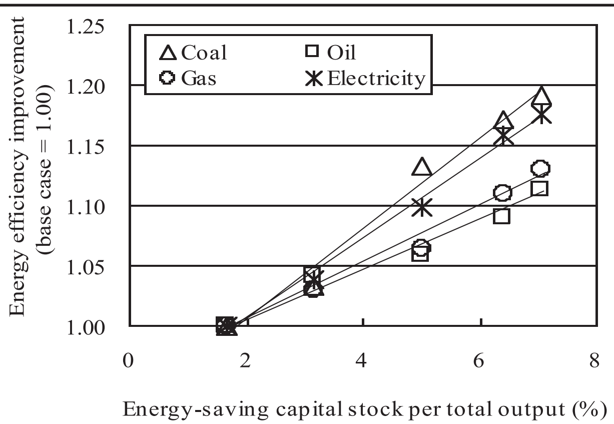
Total income of the household sector gives final demand expenditure, which can either be consumed now to increase present utility, or invested as savings to increase the future utility. The share of the capital formation of each investment good is assumed to be fixed. The investment goods are distributed 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. Unconstrained labor mobility is assumed 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 an important policy option for reducing $CO_2$ emissions, the role of energy-saving investments is considered in this model. In general, the price of equipment rises with its energy-efficiency performance. In this model, such ‘additional costs’ paid for efficient technology are regarded as energy-saving investments. The links between energy-saving investment, accumulated energy-saving capital stock and additional energy efficiency improvement are embodied in the model as endogenous technical change. The sensitivity of equipment cost differentials to energy savings is extracted 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 according to Equation (11), providing the soft-linkage between this dynamic optimization model and the AIM/Enduse model. Equation (10) describes the process of capital stock formation for energy saving. The energy-saving investment (ESI) and the corresponding additional energy efficiency improvement (AE) are determined endogenously. If marginal $CO_2$ abatement costs exceed the cost of an energy-saving investment, then the investment will be made. In this way, additional energy efficiency improvements under the $CO_2$ emission constraint is modeled as induced technology change (ITC).

**Figure 3. Impact of Energy-saving Investments on Energy Efficiency Improvements**




Note: The lines in the figure represent least-square regression in each energy use.

However, this paper considers energy-saving investments in the manufacturing sector alone. Because energy demand systems are unique to sectors, results obtained from the AIM/Enduse model cannot be generalized other sectors such as energy production and the residential. Moreover, the AIM/Enduse model simulates only technologies that are currently in use, up to the year 2030. Beyond 2030, we assume the interplay between investment, energy-efficiency and emissions reductions remains constant at 2030 levels, and that least expected technology innovation occurs until the end of the 21st century.

In addition, due to the lack of data availability in other regions, results derived from the AIM/Enduse model applied to Japan is applied globally, assuming fairly consistent energy demand systems across regions. Given that Japan's economy is among the world's most energy-efficient, this simulation thus show conservative estimates for the effects of energy-saving improvements on a global scale, because greater improvements in energy efficiency is expected to take place in regions other than Japan, especially in developing countries.

### 2.7 $CO_2$ Emissions

Equation (12) gives $CO_2$ emissions that result from the model. $CO_2$ emissions from fossil fuels combustion are taken as endogenous. 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.

The constraint on $CO_2$ emissions is introduced to stabilize atmospheric $CO_2$ concentration on a global scale, whilst 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. In scenario 2, if the price increase due to depletion of fossil fuel resources is sufficiently high, investments in energy-saving technologies will be made. 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, under the "$CO_2$ stabilization case with energy-saving investments" scenario, induced technological change will occur to improve energy-efficiency and achieve stabilization targets – hence ITC plays an important role.

Parameters including autonomous energy efficiency improvements are calibrated to reproduce the level of $CO_2$ emissions and GDP proposed by the Innovation Modeling Comparison Project (IMCP) for the reference case. $CO_2$ emissions from land use and industrial processes in the initial year are adjusted to meet the proposed $CO_2$ emissions. Figure 4 shows the main simulation results of

**Figure 4. Results of Simulations of the Reference Scenario (Area Charts) and Trajectories Proposed by the IMCP (Line Charts)**

Figure 4-(a) GDP

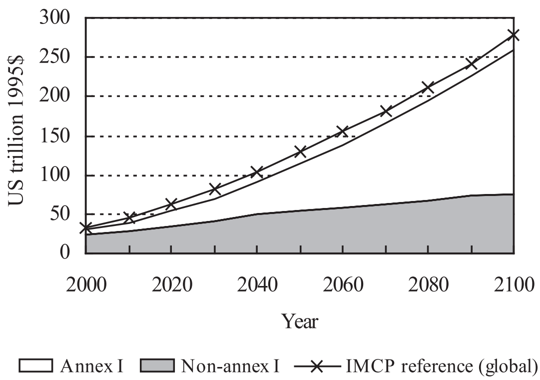
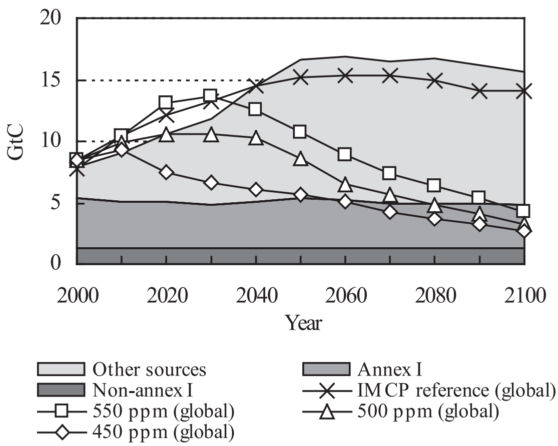



Figure 4-(b) $CO_2$ emissions



the reference scenario and trajectories of $CO_2$ stabilization scenarios proposed by the IMCP. Here, the area charts represent the results for Annex I and Non-Annex I groups in the reference case. Trajectories of emissions under various climate policy targets are also depicted by the line charts in Figure 4(b).

The simulations in this study consider three $CO_2$ concentration stabilization policy scenarios: stabilization at 450, 500, and 550 ppm by the year 2100. Since this model does not include a module for calculating $CO_2$ concentration, we estimate corresponding global $CO_2$ emissions scenarios exogenously. For $CO_2$ reduction simulations, two scenarios—with and without energy-saving investments—are examined in this study.

### 3.1 Cases Without Energy-saving Investments

Figures 5 and 6 show the estimate percentage GDP reductions and the marginal abatement cost of $CO_2$ respectively. In the 450 ppm scenario, total GDP falls by 2.46% compared to the reference scenario over the course of the century, under a 5% annual discounted rate. Under this stringent policy scenario, marginal abatement cost of $CO_2$ reaches 1700 US$/tC in the year 2100. For the 550 ppm stabilization scenario on the other hand, discounted GDP loss is 0.85% compared to the reference scenario and marginal abatement cost of $CO_2$ in 2100 is 76 US$/tC. Under the high $CO_2$ constraint, fossil fuel supply decreases as shown in Figure 7. This implies that mild constraints such as the 550 ppm stabilization case could be achieved by moderate fuel switching. To achieve the 450 ppm scenario, however, requires a drastic fuel transition implying higher costs.

**Figure 5. GDP Reductions Relative to the Reference Case During the 21st Century (Discount Rate: 5%/year)**

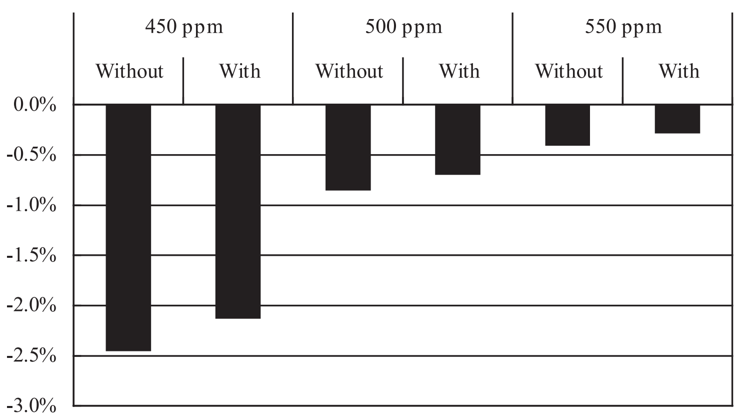


**Figure 6. Changes in Marginal Cost of Reducing $CO_2$ Emissions**

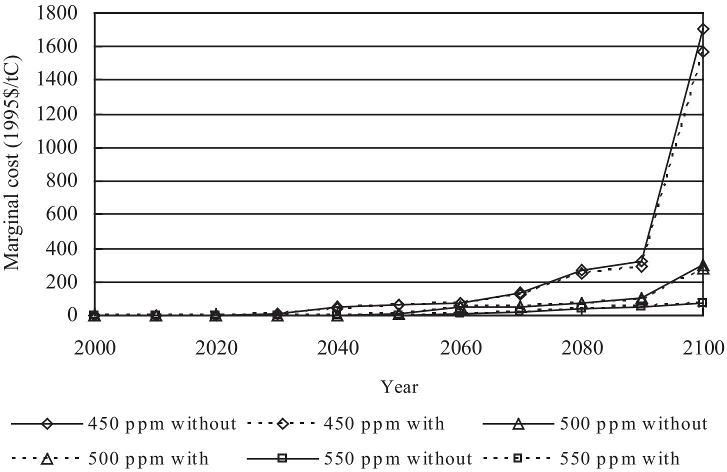
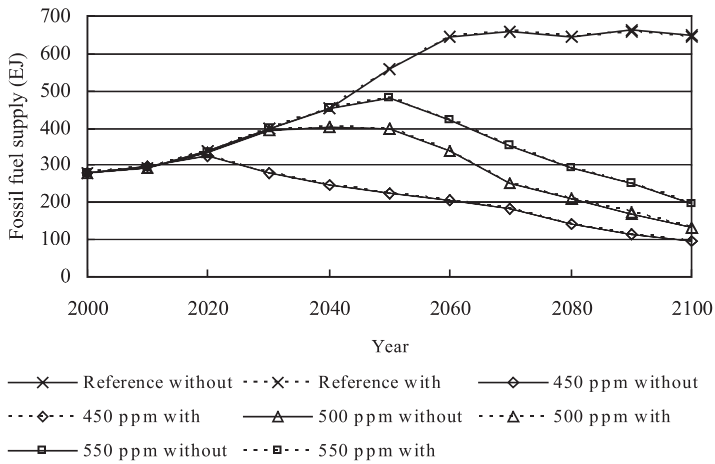



**Figure 7. Changes in Fossil Fuel Supply**




### 3.2 Cases with Energy-saving Investments

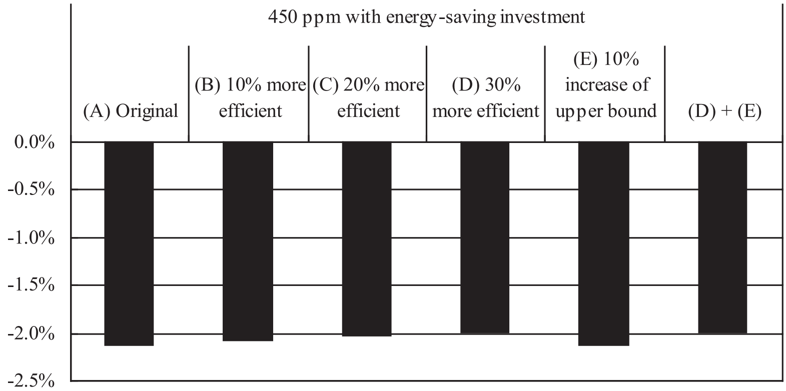
Since energy-saving investments are limited to the manufacturing sector, the effect of the endogenizing energy-saving investments in the overall framework does not appear significant. In the 450 ppm stabilization scenario with energy-saving investments, such investments occur from 2010 onwards. Compared to the same stabilization case without endogenous energy-saving investments, energy-saving investments as a proportion of global GDP increase in the region of 0.2 to 1.0%. For the 450 ppm stabilization case with energy-saving investments, manufacturing production will increase by between 0.017% and 2.3%. Moreover, these manufacturing production activities will induce service demands by between 0.086% and 0.49%. In terms of GDP loss, the simulation shows that existing advanced technologies have the potential to decrease estimated GDP loss from 2.5% to 2.1% for the 450 ppm stabilization case.

Compared to the case without, marginal $CO_2$ abatement costs in the case with energy-saving investments fall by between 6.3% to 11%, after the year 2040. In terms of marginal abatement cost per ton of $CO_2$, energy-saving investments proves a far cheaper option at 4 $/t-C to 135$/t-C compared to the case without. In addition, the additional demand generated by energy-saving investments also contributes to reduce GDP loss due to its income effect.

In contrast, the impact of energy-saving investments in the 550 ppm stabilization scenario is 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, fuel switching emerges as the foremost important transition to reduce $CO_2$ emissions in the economy. As expected, signals for such transition, for example encouraging greater energy-saving investments are stronger under the more stringent $CO_2$ reduction targets.

Figure 8 shows result of the sensitivity analysis carried out to test the responsiveness of GDP levels to varying levels of energy efficiency improvements under the 450 ppm scenario. As energy-efficiency improves by 10%, 20% and 30% compared to the base case shown in Figure 3, GDP loss is reduced by only a small amount. Even if the upper bound of the additional energy efficiency improvement is expanded by 10% compared to the base, it shows only a small impact on percentage GDP change. This is because, as is mentioned in section

**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)**



2.6, energy-saving investments described in equation (11) are introduced only in technologies in use in the manufacturing sector. As a result, even a 30 % additional improvement in energy efficiency in the manufacturing sector creates no technological breakthrough. To cut the GDP loss, not only improvements in existing practical technologies, but the development of new cost-effective technologies is also necessary.

## 4. CONCLUSION

This model simulation focused on the consequences of endogenous investment in energy-saving technologies and evaluated the impact of such investments for reaching different $CO_2$ reduction targets. This study took into account, energy-saving investments in the manufacturing sector, but not in other sectors such as energy production and the residential sector. In addition, because of the lack of available data for other regions, sensitivity of energy-saving investments to energy efficiency improvements in Japan were applied globally in this model.

Despite the restrictive assumptions, simulation results found that when $CO_2$ concentration was set at the 450 ppm stabilization level, discounted total GDP loss during the 21st century relative to that of the reference scenario decrease from 2.46% to 2.12% with investments in energy-saving technologies. However, in the 450 ppm case, reducing GDP loss further requires development of new cost-effective technologies in addition to development of existing ones. The impact of energy-saving investments in the 550 ppm case is relatively small, however, because shifts to low-carbon-intensive energies such as gas and renewable energies occur to a lesser extent.

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 gas (GHG) emissions at around the 475 ppm level, based on the results of the AIM/Impact[Policy] model (Hijioka et al., 2006). In order to achieve this target at minimum costs, the role of energy-saving investments is significant.

Issues arising for further research include improving understanding of the impacts of energy-saving investments, regional disaggregation and activity disaggregation. In particular, having region and sector specific sensitivities of investment level on energy-efficiency improvements would provide more comprehensive estimations. Moreover, there is room for further tests on the robustness of the simulation results taking into account, future uncertainties over fossil fuel reserves, the use of low-cost non-thermal power plants and energy supplies in general. A more detailed assessment of technologies (both existing and new) is necessary to improve long-term climate stabilization scenarios. Lastly, linkages of the model to non-$CO_2$ GHG emissions are also important. To address these issues, further studies including a linkage to the AIM/Impact policy model are planned for the assessment of climate policies.

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