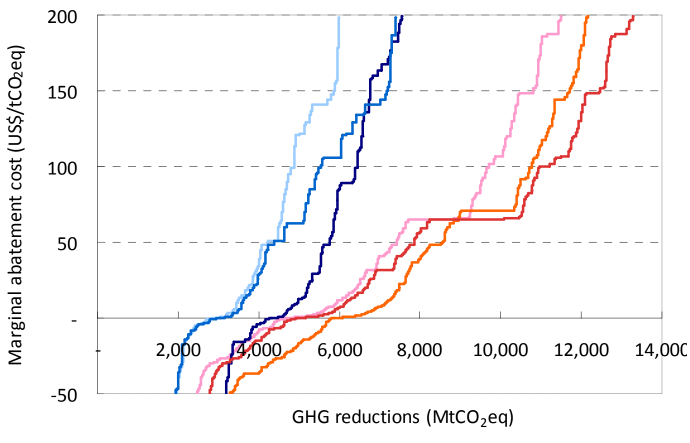
Global Greenhouse Gas Technological Mitigation Potentials and Costs in 2020

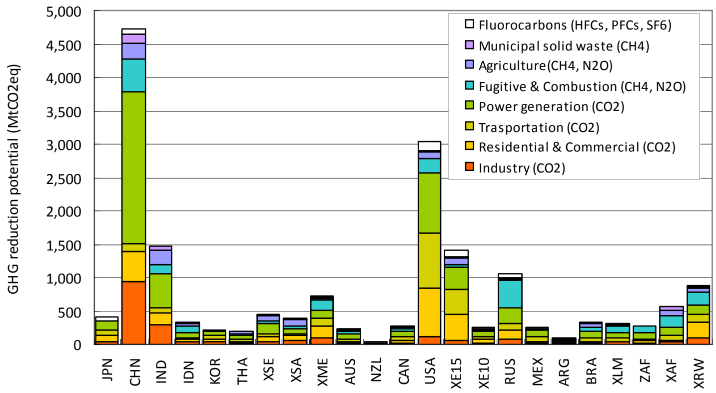
（Second Edition)

Asia-Pacific

AIM

Integrated Model





AIM Interim report
March 2009

AIM Interim Report

2009 March

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Acknowledgements

This research was supported by the Global Environment Research Fund BC-088. We acknowledge the generosity of this fund.

1 Introduction

1.1 Background of this study

Climate change issues have been the focus of international attention in recent decades. The Intergovernmental Panel on Climate Change suggested in the Fourth Assessment Report (AR4) (IPCC, 2007a) that most of the observed increase in globally-averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas (GHG) concentrations. Climate change due to these anthropogenic GHG emissions affects not only the global environment but also the global economy. Especially in the case of developing countries such as those in Asia and Latin America, it is important to consider a balance between their economic growth, which induces rise in GHG emissions, and GHG mitigation policies, which impose economic burdens. Therefore, formal and informal dialogue on the future climate regime after the Kyoto Protocol has increased among those who have a stake in climate change negotiations in recent years, and it is required to assess global GHG mitigation targets and burden-sharing schemes depending on the level of socio-economic characteristics of each region in order to avoid abrupt climate change. For this purpose, it is also required to assess GHG mitigation potentials and these costs, and to look into the importance of international cooperation such as technology transfer mechanisms and financial assistances to developing countries.

There were various studies on GHG mitigation potentials and these costs in each sector. The IPCC Fourth Assessment Report Working Group III (AR4 WG3) (IPCC, 2007b) provides an in-depth analysis of mitigation options, GHG mitigation potentials and costs by reviewing various literature, and the IPCC AR4 WG3 reports mitigation measures by sector in seven chapters on energy supply, transport, buildings, industry, agriculture, forestry, and waste management. In addition, the IPCC AR4 WG3 provides one additional chapter dealing with the cross-sectoral issues that combines information from bottom-up technological studies with results of top-down modeling exercises in various sectors, and summarizes the range of mitigation potentials in seven sectors in OECD, EIT (economies in transition), Non-OECD and all over the World. However, there is no detailed information about the range of mitigation potentials in the major GHG emitting countries or the range of baseline emissions and their socio-economic settings used for estimating those potentials. As is seen in Chapter 11 in the IPCC AR4 WG3, mitigation potentials even at the same level of carbon price will vary widely due to the different settings of socio-economic assumptions, definition of costs, scope of mitigation options, the annual discount rate, assumption of the baseline scenario, and other aspects.

Thus, while comparing a particular study's mitigation potentials and costs with other studies, it is important to clarify various preconditions and understand the differences of definitions, assumptions, and data settings. This study provides information of mitigation potentials by region and by sector as well as data assumptions such as socio-economic and macroeconomic settings, energy service demands and technology options, and then compares those results with the IPCC AR4 WG3.

1.2 Objective of this study

This report is the extensively revised and updated version of the previous study by Hanaoka, et al (2008). This study enlarges the coverage of target sectors and GHGs, improves mitigation options database and makes it consistent in relation to energy service demands across all sectors by using common socio-economic assumptions. In addition, this study takes care of the balance between electricity demand in end-use technologies and energy supply in power generation, thereby preventing double counting or mismatch while estimating mitigation potentials.

Mitigation potentials vary depending on the settings for future energy prices and the technology options, as well as assumptions for the baseline scenario, such as socio-economic and macroeconomic settings and energy service demands. Mitigation potentials also vary depending on the settings for future carbon prices and payback periods when considering a framework of mitigation technology selections. Thus, when discussing mitigation potentials, it is important to show the ranges of these potentials in different case settings.

The objective of this study is thus to estimate GHG emissions, evaluate reduction potentials in various regions throughout the world and to estimate marginal abatement costs (MAC) through 2020. In addition, mitigation potentials and their cost-effectiveness are assessed in terms of their regional, sectoral, and technological aspects.

2 Methodology

2.1 Overview of the model

1) Main output of the model

Industrial goods and services production, energy supply and demand, GHG emissions, air pollutant emissions, waste generation, cost of countermeasures

2) Region

World, classified into 23 geographical regions

3) Year

2000 - 2020

4) Sector

Power generation, industry (iron and steel, cement, other industries), residential and commercial, transportation, agriculture, waste management, fugitive emissions from fuels, and fluorocarbon emissions

5) Technology

About 200 to 300 GHG emissions mitigation technologies are considered. However, it should be noted that this study is based on realistic and currently existing technologies, and there are other mitigation options which are not able to be considered in this study due to the lack of data availability. A lack of data prevents consideration of innovative technologies that may be used in the future.

6) Demand estimation

A large amount of statistical data was used to estimate future service demands, such as industrial goods production, transportation volume, and space heating demand in the residential sector.

7) GHG emissions estimation

GHG emissions and the potential for their reduction are estimated by using a bottom-up optimization model with detailed technology selection framework. In the model, technologies are determined under the criteria of total cost minimization.

2.2 Structure of the model

Figure 1 shows overall structure of AIM/Enduse[Global]. The model consists of three parts: a macroeconomic model, a service demand model, and a technology bottom-up model.

First, macroeconomic indicators, such as GDP and sector-wise value added in real terms, are estimated by the Socio-economic Macro Frame model, which is a supply-side macroeconomic model that uses future population as an input. Second, service demands, such as steel production, cement production, transportation volume, and energy service demand in the residential and commercial sector, are estimated using several service demand models. These models use macroeconomic indicator estimates generated by the Socio-economic Macro Frame model. Finally, GHG emissions and the potential for their reduction are estimated by using a bottom-up optimization model with detailed technology selection framework, which is associated with a technology database that contains approx. 200 to 300 GHG emission mitigation technologies. The model simulates the diffusion of those technologies in the future under several constraints, such as the satisfaction of service demand. The technologies are determined under the criteria of total cost minimization.

The technology bottom-up model first estimates the emissions and final energy consumption in the final demand sectors, such as the industry and residential sectors. It then uses the given final energy demand to estimate the emissions and primary energy consumption for the power generation sector. Finally, it uses the given primary energy demand to estimate fugitive emissions from fuel productions.

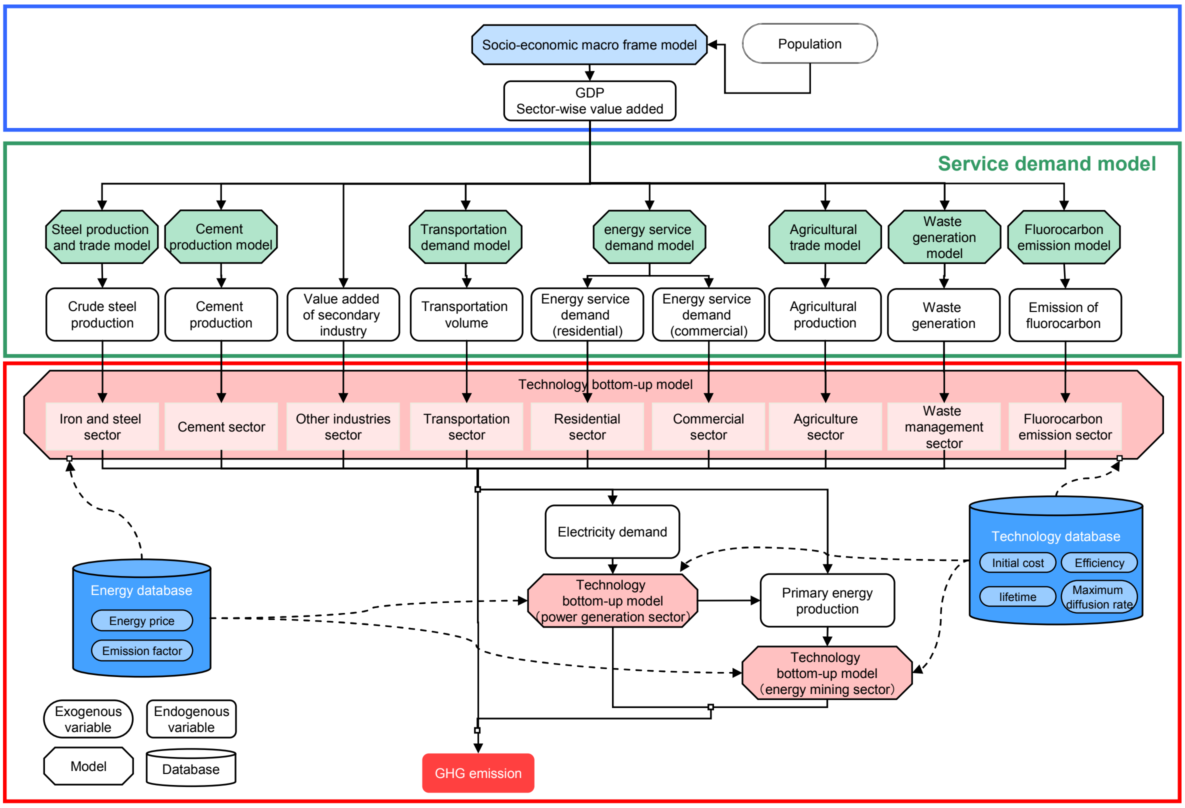


Figure 1 Structure of AIM/Enduse[Global]

2.3 Definition of regions, gases and sectors

There are different approaches for regional aggregations depending on the purpose of the analysis. This study focused on the major GHG emitting regions, especially the Asian regions, and covered 23 geographical world regions as shown in Figure 2. As for the gases and sectors, this study covered six GHGs regulated under the Kyoto Protocol, in multiple sectors such as power generation, industry, residential and commercial, transportation, agriculture, waste and fluorocarbon emissions sectors as shown in Table 1. Technology database were developed and emission reduction potentials and their costs were evaluated sector-wise and region-wise, based on a bottom-up approach.

Table 1 Target sectors and gases

GHG	Sector
CO_2, CH_4, N_2O	Power generation
	Industry
	Transport
	Residential & commercial
CH_4, N_2O	Agriculture
CH_4	Municipal solid waste
	Fugitive emissions from fuels
HFC, PFC, SF_6	Fluorocarbon emissions

Table 2 World 23 regions in AIM/Enduse[Global]

Code	Region		Code	Region	
JPN	Japan	Developed	CAN	Canada	Developed
CHN	China	Developing	USA	United States	Developed
IND	India	Developing	XE15	EU15 in Western EU	Developed
IDN	Indonesia	Developing	XE10	EU10 in Eastern EU	Developed
KOR	Korea	Developing	RUS	Russia	Developed
THA	Thailand	Developing	ARG	Argentine	Developing
XSE	Other South-east Asia	Developing	BRZ	Brazil	Developing
XSA	Other South Asia	Developing	XLM	Other Latin America	Developing
XME	Middle East	Developing	XAF	Other Africa	Developing
AUS	Australia	Developed	XRW	Rest of the World	Developing
NZL	New Zealand	Developed			

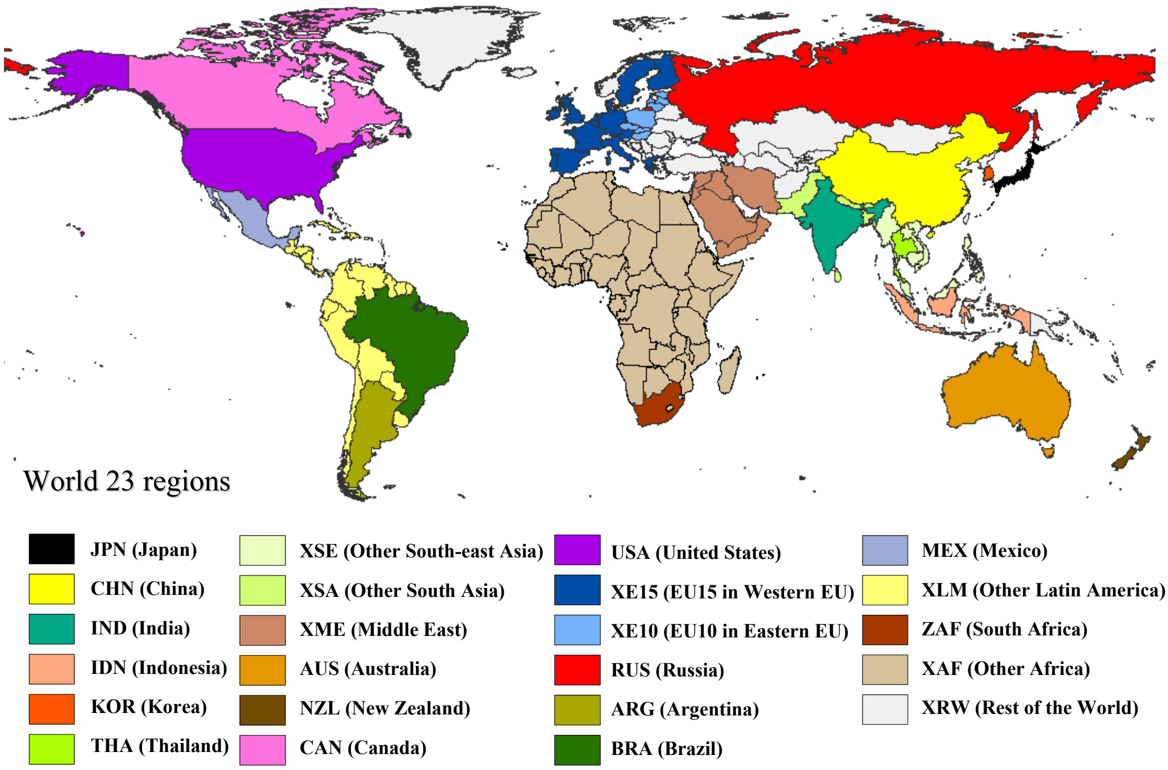


Figure 2 World 23 regions in AIM/Enduse[Global]

2.4 Definition of reduction potentials and marginal abatement costs

Firstly, the terminology used in this study should be clearly defined. In this study, a "service" is defined as "a measurable need within a sector that can be satisfied by supplying an output from a device", and it can be defined in either tangible or abstract terms. Thus, "service demand" refers to the quantified demand created by a service; i.e. service outputs from devices satisfy service demands. Examples of service demands include the demand of crude steel products (tangible, intermediate output from blast furnaces and converters), person-km traveled by road (abstract, final output of road transport vehicles), and heat energy for raising superheated steam (abstract, intermediate output from heat exchangers in combined cycle power plants). It must be noted here that concepts of 'final service' and 'intermediate service' are defined by the users for convenience in this study, and may not necessarily imply real-life interpretations of these terms.

Secondly, the definition of reduction potentials needs to be clarified. According to the IPCC AR4(2007b), reduction potential is described as "the scale of GHG reductions that could be achieved, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced)", and a baseline is defined as "the reference from which an alternative outcome can be measured, e.g. a non-intervention scenario is used as a reference in the analysis of intervention scenarios". The reduction potentials and their costs vary not only the key data-settings such as the rate of technology development and diffusion, the cost of future technology, future energy and carbon prices, but also the settings of activity levels under different baselines. In this study, a technology frozen case, which was often used in the bottom-up analysis in some papers reviewed in the IPCC AR4(2007b), was set as the baseline, and the future share and energy efficiency of standard technologies were fixed at the same level as in the base year. Therefore, reduction potentials in this study are defined as "reduction amounts which are estimated by comparing the effect of introduction of new mitigation technologies in the target year, target region and target sector as compared to the effect of standard technologies fixed at the same level as in the base year". Thus, mitigation costs are defined as the additional costs, including capital cost and operational cost, that are required for introducing new mitigation measures. As there are various technology options and scales in different sectors and regions, the marginal abatement cost varies widely. Sometime the marginal abatement cost can show negative net cost because a given technology may yield enough energy cost savings to more than off-set the costs of adopting and using the earlier technology.

2.5 Marginal abatement cost curves

2.5.1 Outline of marginal abatement cost curves

Reduction potentials and mitigation costs were estimated by using a detailed technology options database developed in the AIM/Enduse[Global] model. Based on the database, the marginal abatement cost curve in a target year (*t*), target region/sector (*i*) and service type (*j*) is described as follows. Firstly, the GHG emission reduction of an energy device *l*, $\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}}$, additional cost of energy device *l*, $\Delta\hat{C}_{l,i}^{t}$, and maximum potential of stock of energy device *l*, $\Delta S_{l,i}^{\max,t}$, in a time period (year) *t* were calculated. Next, the abatement cost of unit reduction, $\Delta\hat{C}_{l,i}^{t} / \Delta\hat{Q}_{l,i}^{t,GHG}$, was plotted along the y-axis, and GHG emission reduction of an energy device *l*, $\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}}$, was plotted along the x-axis in order of ascending abatement cost per unit reduction. $\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}}$, $\Delta\hat{C}_{l,i}^{t}$, and $\Delta S_{l,i}^{\max,t}$ represent the differences between the respective values in the time period *t* and in the base year t_0. The suffix of indices and sets are defined as follows; *i* : region/sector, *j* : service type, *k* : energy type, *l* : energy device (i.e. technology option), *m* : gas type, *t* : time period (year), 0 : base year, and $\hat{}$: quantity per unit[note1)].

[note1)] For some parameters this indicates quantity per unit of device and for others quantity per unit of energy use.

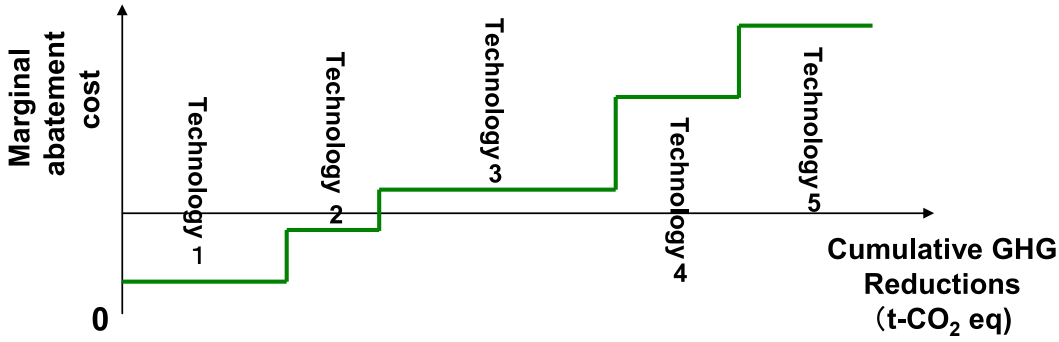


Figure 3 Schematic of marginal abatement cost curve

2.5.2 Formulations

Gas emission per unit service supply $Q_{j,i}^{t,m}$

Emission of gas *m* per unit supply of service *j* in region/sector *i* in time period *t*, $Q_{j,i}^{t,m}$, is formulated as follows:

$$Q_{j,i}^{t,m} = \sum_{l \in W_j} X_{l,i}^{t} \cdot \hat{e}_{l,i}^{t,m} \tag{1}$$

where,

$X^t_{l,i}$: Operating quantity of energy device *l* in region/sector *i*. Formula (4).

$\hat{e}_{l,i}^{t,m}$: Emission of gas *m* per unit operation of energy device *l* in region/sector *i* in time period *t*. Formula (2).

Gas specific emission $\hat{e}_{l,i}^{t,m}$

Emission of gas *m* per unit operation of energy device *l* in region/sector *i* in time period *t*, $\hat{e}_{l,i}^{t,m}$, is formulated as follows:

$$\hat{e}_{l,i}^{t,m} = \hat{f}_{0,l}^{t,m} + \sum_{k} \hat{f}_{k,l}^{t,m} \cdot \left(1 - \xi_{k,l,i}^{t}\right) \cdot \hat{E}_{k,l,i}^{t} \cdot U_{k,l} \tag{2}$$

where,

$\hat{f}_{0,l}^{t,m}$: Emission of gas *m* per unit operation of energy device *l* other than energy combustion in time period *t*. Exogenous variable.

$\hat{f}_{k,l}^{t,m}$: Emission of gas *m* of energy device *l* per unit consumption of energy *k* in time period *t*. Exogenous variable.

$\xi_{k,l,i}^{t}$: Energy saving ratio due to maintenance and improvement of usage of energy *k* by energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$\hat{E}_{k,l,i}^{t}$: Consumption of energy *k* by energy device *l* per unit operation in time period *t*. Exogenous variable.

$U_{k,l}$: Proportion of energy *k* used in energy device *l*. Exogenous variable.

Service demand $D^t_{j,i}$

Demand for service *j* in region/sector *i* is equal to the summation of the service supply of energy device *l* that can meet the demand for service *j*:

$$D^t_{j,i} = \left(1 + \Psi^t_{j,i}\right) \cdot \sum_{l \in W_j} \hat{A}^t_{l,j,i} \cdot X^t_{l.i} \tag{3}$$

where,

$D^t_{j,i}$: Service demand for service *j* in region/sector *i* in time period *t*. Exogenous variable.

$\Psi^t_{j,i}$: Improvement in supply-efficiency of service *j* in region/sector *i* in time period *t*. Exogenous variable.

$\hat{A}^t_{l,j,i}$: Supply-quantity of service *j* per unit operation of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$X^t_{l,i}$: Operating quantity of energy device *l* in region/sector *i* in time period *t*. Formula (4)

Operating quantity of energy device $X_{l,i}$

The operating quantity of energy device *l* in region/sector *i* in time period *t*, $X_{l,i}$ is formulated as follows:

$$X^t_{l,i} = \frac{S^t_{l,i}}{1 + \Lambda^t_{l,i}} \tag{4}$$

where,

$S^t_{l,i}$: The quantity remaining in time period *t* of device *l* that existed in the base year. Formula (7).

$1+\Lambda^t_{l,i}$: Operating rate of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

Annual cost of energy device $\hat{C}^t_{l,i}$

The annual cost of energy device *l* in region/sector *i* in time period *t*, including the fixed, energy, and maintenance costs, $\hat{C}^t_{l,i}$, is formulated as follows:

$$\hat{C}^t_{l,i} = \hat{B}^t_{l,i} \cdot (1 - SC_{l,i}) \cdot \frac{\alpha_i (1+\alpha_i)^{T_{l,i}}}{(1+\alpha_i)^{T_{l,i}} - 1} + \frac{\hat{g}^t_{0,l,i} + \sum_k g^t_{1,k,i} \cdot \left(1 - \xi^t_{k,l,i}\right) \cdot \hat{E}^t_{k,l,i}}{1 + \Lambda^t_{l,i}} \tag{5}$$

where,

$\hat{B}^t_{l,i}$: Fixed cost of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$SC_{l,i}$: Subsidy rate of energy device *l* in region/sector *i*. Exogenous variable.

α_i : Interest rate. Exogenous variable.

$T_{l,i}$: Lifetime of energy device *l*. Exogenous variable.

$\hat{g}^t_{0,l,i}$: Maintenance and operating cost per unit operation of energy device *l*, other than fuel cost in time period *t*. Exogenous variable.

$\hat{g}^t_{1,k,i}$: Price of energy *k* per unit consumption in time period *t*. Exogenous variable.

$\xi^t_{k,l,i}$: Energy saving ratio due to maintenance and improvement of usage of energy *k* by energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$\hat{E}^t_{k,l,i}$: Consumption of energy *k* by energy device *l* per unit operation in time period *t*. Exogenous variable.

Annual cost of service supply $C^t_{j,i}$

The annual cost of supplying service *j,* including the fixed, energy, and maintenance costs, in region/sector *i* in time period *t*, $C^t_{j,i}$, is formulated as follows:

$$C^t_{j,i} = \sum_{l \in W_j} \hat{C}^t_{l,i} \cdot S^t_{l,i} \qquad (6)$$

where,

$\hat{C}^t_{l,i}$: Annual cost of supplying service *j,* including the fixed, energy, and maintenance costs, in time period *t*. Formula (5).

$S^t_{l,i}$: Stock remaining in time period *t* of energy device *l* that existed in the base year. Formula (7).

Remaining stock of energy device $S^t_{l,i}$

The stock of an energy device recruited in a given year will retire at the end of its life, with its quantity reducing exponentially during its lifetime. The remaining stock of energy device *l* in region/sector *i* in time period *t*, $S^t_{l,i}$, is formulated as follows:

$$S^t_{l,i} = S^0_{l,i} \cdot e^{-\frac{(t-t_0)}{T_{l,i}}} \qquad (7)$$

where,

$S^0_{l,i}$: Stock of energy device *l* in region/sector *i* in the base year. Exogenous variable.

t_0 : Base year.

t : Time period (years).

$T_{l,I}$: Lifetime of energy device *l* in region/sector *i*. Exogenous variable.

Gap between service demand and service supply of remaining stock $\Delta D^{\text{init},t}_{j,i}$

The gap between the demand for service *j* and the summation of the service supply of remaining stock that can supply service *j* in region/sector *i* in time period *t*, $\Delta D^{init,t}_{j,i}$, is formulated as follows:

$$\Delta D^{\text{init},t}_{j,i} = D^t_{j,i} - \sum_{l \in W_j} S^0_{l,i} \cdot e^{-\frac{(t-t_0)}{T_{l,i}}} \cdot \frac{1+\Psi^t_{j,i}}{1+\Lambda^t_{l,i}} \cdot \hat{A}^0_{l.j.i} \qquad (8)$$

where,

$S^0_{l,i}$: Stock of energy device *l* in region/sector *i* in the base year. Exogenous variable.

$1+\Lambda^t_{l,i}$: Operating rate of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$\Psi^t_{j,i}$: Improvement in supply-efficiency of service j in region/sector *i* in time period *t*. Exogenous variable.

$\hat{A}^0_{l,j,i}$: Supply-quantity of service *j* per unit operation of energy device *l* in the base year. Exogenous variable.

Reduction of gas emission per unit of service $\Delta\hat{Q}_{l,i}^{t,m}$ **,** $\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}}$

The reduction of emission of gas *m* per unit of service *j* of energy device *l* in region/sector *i* in time period *t*, $\Delta\hat{Q}_{l,i}^{t,m}$, is formulated as follows:

$$\Delta\hat{Q}_{l,i}^{t,m} = \frac{Q_{j,i}^{0,m}}{D_{j,i}^{0}} - \frac{\hat{e}_{l,i}^{t,m}}{\hat{A}_{l,j,i}^{t}\left(1+\Psi_{j,i}^{t}\right)} \tag{9}$$

$$\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}} = \sum_{m} GWP_m \cdot \Delta\hat{Q}_{l,i}^{t,m} \tag{10}$$

where,

$Q_{j,i}^{0,m}$: Emission of gas *m* per unit supply of service *j* in region/sector *i* in the base year. Formula (1).

$D^{0}_{j,i}$: Service demand for service *j* in region/sector *i* in the base year. Exogenous variable.

$\hat{e}_{l,i}^{t,m}$: Emission of gas *m* from energy device *l* per unit operation in time period *t*. Formula (2).

$\hat{A}_{l,j,i}^{t}$: Supply-quantity of service *j* per unit operation of energy device *l* in time period *t*. Exogenous variable.

$\Psi^{t}_{j,i}$: Improvement in supply-efficiency of service *j* in region/sector *i* in time period *t*. Exogenous variable.

GWP_m : Global warming potential of gas *m*.

Additional annual cost per unit of service of energy device $\hat{C}_{l,i}^{t}$

The additional annual cost per unit of service *j* of energy device *l* in region/sector *i*, $\Delta\hat{C}_{l,i}^{t}$, is the difference between the cost in the base year t_0 and that in given year *t*:

$$\Delta\hat{C}_{l,i}^{t} = \frac{C_{j,i}^{0}}{D_{j,i}^{0}} - \frac{\hat{C}_{l,i}^{t}\cdot(1+\Lambda_{l,i}^{t})}{\hat{A}_{l,j,i}^{t}\cdot(1+\psi_{j,i}^{t})} \tag{11}$$

where,

$C^{0}_{j,i}$: Annual cost of supplying service *j,* including the fixed, energy, and maintenance costs, in the base year $\boldsymbol{t_0}$. Formula (6).

$D^{0}_{j,i}$: Service demand for service *j* in region/sector *i* in the base year t_0. Exogenous variable.

$\hat{C}_{l,i}^{t}$: Annual cost of energy device *l,* including the fixed, energy, and maintenance costs, in time period *t*. Formula (5).

$\hat{A}_{l,j,i}^{t}$: Supply quantity of service *j* per unit operation of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$1+\Lambda^{t}_{l,i}$: Operating rate of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$\Psi^{t}_{j,i}$: Improvement in supply-efficiency of service *j* in region/sector *i* in time period *t*. Exogenous variable.

Abatement cost per unit reduction of energy device $AC^t_{l,i}$

The abatement cost per unit reduction of energy device *l* in region/sector *i* in time period *t*, $AC^t_{l,i}$, is formulated as follows:

$$AC^t_{l,i} = \frac{\Delta \hat{C}^t_{l,i}}{\Delta \hat{Q}^{t,\mathrm{GHG}}_l} \tag{12}$$

where,

$\Delta \hat{C}^t_{l,i}$: Additional annual cost per unit of service *j* of energy device *l* in region/sector *i* in time period *t*. Formula (11).

$\Delta \hat{Q}^{t,\mathrm{GHG}}_{l,i}$: Reduction of GHG emission per unit of service *j* of energy device *l* in region/sector *i* in time period *t*. Formula (10).

Maximum share $\theta^t_{l,j,i}$

The maximum share of energy device *l* for service *j* in region/sector *i*, $\theta^t_{l,j,i}$, is the smaller of the ratio of the introduction potential and the exogenous value, as expressed below:

$$\theta^t_{l,j,i} = Min\left(\frac{\Delta D^{init,t}_{j,i} + S^0_{l,i} \cdot e^{-\frac{(t-t_0)}{T_{l,i}}} \cdot \hat{A}^t_{l,j,i} \cdot (1+\Psi^t_{j,i})/(1+\Lambda^t_{l,i})}{D^t_{j,i}}, \theta'^t_{l,j,i}\right) \tag{13}$$

where,

$\Delta D^{\mathrm{init},t}_{j,i}$: Gap between demand for service *j* and summation of service supply of remaining stock that can supply service *j* in region/sector *i* in time period *t*. Formula (8).

$S^0_{l,i}$: Stock of energy device *l* in region/sector *i* in base year. Exogenous variable.

$1+\Lambda^t_{l,i}$: Operating rate of energy device *l* in region/sector *i*. Exogenous variable.

$\Psi^t_{j,i}$: Improvement in supply-efficiency of service j in region/sector *i*. Exogenous variable.

$\hat{A}^t_{l,j,i}$: Supply-quantity of service *j* per unit operation of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$T_{l,i}$: Lifetime of energy device *l*. Exogenous variable. .

$D^t_{j,i}$: Service demand for service *j* in region/sector *i* in time period *t*. Exogenous variable.

$\theta'^t_{l,j,i}$: Maximum share of energy device *l* for service *j* in region/sector *i*. Exogenous variable.

Maximum service supply of recruited energy device $\Delta D^t_{l,j,i}$

It is assumed that energy devices are introduced preferentially in ascending order of additional cost. The maximum supply of service *j* by recruited energy device *l* in region/sector *i* is equal to the service quantity that cannot be supplied by energy devices whose additional cost is lower than that of energy device *l*:

$$\Delta D^t_{l,j,i} = D^t_{j,i} - \sum_{l' \in (AC^t_{l',i} < AC^t_{l,i})} \frac{S^{\max,t}_{l',i} \cdot \hat{A}^t_{l',j,i} \cdot (1+\Psi^t_{j,i})}{(1+\Lambda^t_{l',i})}, \tag{14}$$

$$S^{\max,t}_{l,i} = \frac{D^t_{j,i} \cdot \theta^t_{l,j,i} \cdot (1+\Lambda^t_{l,i})}{\hat{A}^t_{l,j,i} \cdot (1+\Psi^t_{j,i})}, \tag{15}$$

where,

$D^{t}_{j,i}$: Service demand for service *j* in region/sector *i* in time period *t*. Exogenous variable.

$\theta^{t}_{l,j,i}$: Maximum share of energy device *l* for service *j* in region/sector *i*. Formula (13).

$\hat{A}^{t}_{l,j,i}$: Supply-quantity of service *j* per unit operation of energy device *l* in time period *t*. Exogenous variable.

$1+\Lambda^{t}_{l,i}$: Operating rate of energy device *l* in region/sector *i* in time period *t*. Exogenous variable.

$\Psi^{t}_{j,i}$: Improvement in supply-efficiency of service *j* in region/sector *i* in time period *t*. Exogenous variable.

Reduction potential of GHG emission $\Delta Q^{t,\mathrm{GHG}}_{\mathrm{pot},l,i}$

The reduction potential of GHG emission of energy device *l* in region/sector *i* in time period *t*, $\Delta Q^{t,\mathrm{GHG}}_{\mathrm{pot},l,i}$, is formulated as follows:

$$\Delta Q^{t,\mathrm{GHG}}_{\mathrm{pot},l,i} = \Delta \hat{Q}^{t,\mathrm{GHG}}_{l,i} \cdot \Delta D^{t}_{l,j,i}, \qquad (16)$$

where,

$\Delta \hat{Q}^{t,\mathrm{GHG}}_{l,i}$: Reduction of GHG emission per unit of service *j* of energy device *l* in region/sector *i* in time period *t*. Formula (10).

$\Delta D^{t}_{l,j,i}$: Maximum supply of service *j* by recruited energy device *l* in region/sector *i*. Formula (14).

2.6 Global Warming Potential values in this report

The environmental impacts of non-CO_2 GHGs on global warming are calculated in tons of CO_2 equivalent, by using the value of Global Warming Potential (GWP) which represents "the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace gas expressed relative to that of 1 kg of a reference gas"(IPCC, 2001). These GWP values, which are defined by the IPCC, represent the direct global warming potentials relative to CO_2 by injection of infrared absorbing gases into the atmosphere. These values do not include indirect effects, for example, other warming or cooling effects by the chemical transformations of greenhouse gases. It should be noted that the GWP values are defined differently in *Climate Change 1995*(IPCC, 1995), *Climate Change 2001*(IPCC, 2001), and *Climate Change 2007*(IPCC, 2007a)), as shown in Table 3. The GWP values reported in the *Climate Change 2007*(IPCC, 2007a) are the latest, however in order to compare this study with other results reviewed in the IPCC AR4 WG3, the GWP values in *Climate Change 1995*(IPCC, 1995) whose values are also used for GHGs national inventory reports, because of the stipulation in the Kyoto Protocol, are considered in this study. For example, the direct GWPs of HFCs per unit of weight range from about a few dozen to a hundred thousand times larger than that of CO_2. Atmospheric lifetimes of different GHGs vary from several dozen years to tens of thousands years. Thus the GWP values vary widely according to the time horizon over which the calculation is considered. The IPCC defined these GWP values in the time horizon of 20 years, 100 years, and 500 years. Table 3 shows the GWP values in the time horizon of 100 years which is normally used as the standard.

Table 3 The Global Warming Potentials of major non-CO_2 GHGs

Species	Chemical Formula	Climate Change 1995	Climate Change 2001	Climate Change 2007
Methane	CH_4	21	23	25
Nitrous oxide	N_2O	310	296	298
HFCs				
HFC-23	CHF_3	11700	12000	14800
HFC-32	CH_2F_2	650	550	675
HFC-125	C_2HF_5	2800	3400	3500
HFC-134a	CH_2FCF_3	1300	1300	1430
HFC-143a	CF_3CH_3	3800	4300	4470
HFC-152a	$C_2H_4F_2$	140	120	124
HFC-227ea	C_3HF_7	2900	3500	3220
HFC-236fa	$C_3H_2F_6$	6300	9400	9810
HFC-245ca	$C_3H_3F_5$	560	640	640
HFC-43-10mee	$C_5H_2F_{10}$	1300	1500	1640
PFCs				
Perfluoromethane	CF_4	6500	5700	7390
Perfluoroethane	C_2F_6	9200	11900	12200
Perfluoropropane	C_3F_8	7000	8600	8830
Perfluorobutane	$C_4 F_{10}$	7000	8600	8860
Perfluorocyclobutane	c-C_4F_8	8700	10000	10300
Perfluoropentane	C_5F_{12}	7500	8900	9160
Perfluorohexane	C_6F_{14}	7400	9000	9300
SF_6				
Sulphur hexafluoride	SF_6	23900	22200	22800

3 Data assumptions

3.1 Overview

This study is based on a bottom-up analysis, wherein, to evaluate mitigation potentials at regional and global levels, it is necessary to first determine future service demands in each service and sector exogenously. These service demands are estimated sector-wise and region-wise based on several models developed for this study. The data for these models come from several dozens of international and national statistics and outlooks. As for the socio-economic drivers, future population are set based on the UN World Population Prospects(2007) and GDP growth are set based on the Socio-economic Macro Frame model. The future service demands are originally estimated in this study based on these population and GDP data. Thus, this study takes into account consistency of socio-economic assumptions not only in the same sector across countries but also among different sectors in global regions. In addition, this study links the energy supply side and demand side, thus electricity supply and demand is consistent across sectors and regions. Current domestic and international energy prices are based on Energy Prices and Taxes (IEA, 2007b), while future global energy prices are based on assumptions made by the Institute of Energy Economics, Japan (personal communication, 2009), that are between the estimates in World Energy Outlook 2007 (IEA, 2007a) and World Energy Outlook 2008 (IEA, 2008). The base year and the target year are set as 2005 and 2020 respectively.

It is important to note that, in this study, it is necessary to determine service demands exogenously. Hence this study does not take into account spillover effects due to introducing mitigation measures, such changes in the industrial structure, changes of service demands, and changes in technology and energy price.

In this study, mitigation costs are measured by capital cost and operational cost; i.e. capital cost, which is the initial investment cost required to recruit one unit of a device, and operational cost, which is the annual cost incurred in operating one unit of a device. Mitigation costs vary depending on the settings for the annual discount rate for specific investments. In this study, the annual discount rate for specific investments is determined exogenously so as to exogenously fit the rate of the payback period. The payback period represents the period of time required for the return on an investment, such as energy savings, to break cost on capital cost and operational cost. As mitigation costs vary depending on the settings, shorter payback periods are obviously preferable to longer payback periods, especially for private industries that assume high risk for investing in energy conserving technologies. The capital recovery factor $[P \to M]_{T_L}^{\alpha}$ is formulated as Equation (17), where α : annual discount rate and T_L : the lifetime of energy device *l*. Thus, the correlation between the annual discount rate for specific investments and the payback period depends on the lifetime of energy device *l*.

$$[P \to M]_{T_L}^{\alpha} = \frac{\alpha \cdot (\alpha + 1)^{T_L}}{(1+\alpha)^{T_L} - 1} \qquad (17)$$

In developing countries and economies in transition, economy is unstable and investment risk is very high, so that payback period should be considered shorter (i.e. annual discount rate is larger) than other countries. Moreover, sense of values and stability of economy vary across countries, so that valuation standards of annual discount rates should be different across regions. However, to evaluate mitigation potentials comparatively region by region, country risks are not taken into account in this study and the same level of annual discount rates are assumed across the world as shown in Table 4

Table 4 Setting of payback period

Case	Sector	Setting of payback period	Example of payback period (Lifetime use in the model)
Reference case	Industry, Residential, Commercial, Transport	Payback periods were set as three years in the industry sector and five years in the residential and commercial sector respectively in a report by Global Environment Committee of Central Environment Council (2001), and also the Energy Conservation Center, Japan (1998) conducted an questionnaire survey on all sectors and reported the average payback period was 4.4 years across sectors. In addition, based on the questionnaire survey which was executed for companies and households in Japan related to this study showed that the payback period of investment on energy saving technology was about three years. Thus, for energy-related sectors such as industry, residential, commercial and transport, where a rate of technology improvement is high and there are technology perspectives on the temporal horizon, the payback period is assumed as around three years across these sectors. (i.e. the annual discount rate is set at 33% which corresponds to approximately three years payback period).	Residential equipments: 3 years (10-15years) Car, truck, bus: 3 years (8-12 years)
	Power plant Industry plant Infrastructure House insulation	he power generation sector is considered as a kind of public industry that takes into account low investment risks by considering governmental supports. Moreover, facilities with long lifetimes, such as industrial plants, public transportation (trains, ships, aircraft), and thermal insulation for homes and buildings, have longer payback periods to reduce investment risks. Therefore, the payback period is considered longer and assumed as around ten years. (i.e. the annual discount rate is set at 10 % which corresponds to approximately nine to ten years payback period under the assumption of 30 years lifetime for power plants).	Plant: 9-10 years (30 years) Train, ship, aircraft: 8-9 years (20 years) Insulation housing: 9-10 years (30years)
	Agriculture Waste Fluorocarbons	The features of the agriculture, waste, and fluorocarbon emission sectors are different from those of energy-related sectors. In these sectors, a rate of technology improvement is slow and there is less technology perspective in a short term, the payback period should be assumed longer enough to consider the lifetime of technology options. (i.e. in this study, it is set at a five % annual discount rate [note 1]).	Agriculture: 1-11 year (1-15 year) MSW: 10-16 year (15-30 year) Fluorocarbons: 1-13 year (1-20year)
Policy case	All sectors	Assuming shorter payback periods, as described in the reference case, only technologies with a low investment risk and a certain level of energy conservation are introduced. In order to promote more measures for energy conservation, policy measures should allow adequately long payback periods corresponding to about 50~70% of the technology's lifetime. (i.e. a 5% annual discount rate [note 1] was considered across all sectors and all regions).	Residential equipments: 7-10 years (10-15years) Car, truck, bus: 6-9 years (8-12 years) Plant: 14-15 years (30 years) Train, ship, aircraft: 12-13 years (20 years) Insulation housing: 15-16 years (30years)

Note 1) Correlation of annual discount rate and payback period depends on the lifetime of technology. For example, payback period is 15.4 and 7.7 years when the lifetime of technology is 30 years and 10 years respectively under a five % annual discount rate.

3.2 Socio-economic and macroeconomic settings

3.2.1 Population

1) Overview

The population growth in 23 regions is set based the future prospects at medium variant by UN World Population Prospects(2007a). This section introduces how population data are aggregated into 23 regions in this study and explains the characteristics of population growth. The population scenario described here is used for all sectors in this study.

2) Methodology and assumption

- UN (2007a) edited observed population changes from 1950 to 2005 and estimated future population prospect in 218 countries. In this study, these data are aggregated into 23 countries and regions.
- It seems that UN(2007a) does not include data of Taiwan, thus this study also reviewed population data from 1971 to 2007 based on Taiwan statistical data book(CEPD, 2007a) and future population prospects at medium variant from 2008 to 2020 based on Population Projections for Taiwan Areas(CEPD, 2007b).

3) Results in 23 regions

- Population in 23 regions shown as Table 5. Global population is 6.5 billion in 2005 and it is expected to reach approximately 7.7 billion in 2020 which is 1.18 times more than the population in 2005.
- Population growth in developing countries is significant, for example in 2020, 1.43 billion in China (1.08 times from 2005 levels), 1.38 billion in India (1.22 times from 2005 levels) and 1.22 billion in Other Africa in 2020 (1.39 times from 2005 levels). The population in Asia regions including China and India rises to 4.1 billion which accounts for 54% of the global population in 2020.

Table 5 Population in 23 regions

	Population			Population 16 - 64 year-old		
	2005	2020	2020/2005	2005	2020	2020/2005
Japan	128	124	0.97	85	75	0.88
China	1,321	1,430	1.08	934	998	1.07
India	1,134	1,379	1.22	704	918	1.30
Indonesia	227	264	1.16	150	183	1.22
Korea	48	49	1.03	34	35	1.02
Thailand	63	68	1.08	44	47	1.05
Other South-east Asia	268	327	1.22	169	220	1.30
Other South Asia	384	500	1.30	229	319	1.39
Middle East	192	254	1.33	119	166	1.40
Australia	20	23	1.15	14	15	1.10
New Zealand	4	5	1.13	3	3	1.10
Canada	32	37	1.13	22	24	1.08
United States	300	343	1.14	201	222	1.10
EU15 in Western EU	387	399	1.03	258	256	0.99
EU10 in Eastern EU	74	72	0.97	52	48	0.93
Russia	144	132	0.92	102	92	0.90
Mexico	104	121	1.16	66	82	1.23
Argentine	39	44	1.15	25	29	1.18
Brazil	187	220	1.18	123	148	1.20
Other Latin America	228	275	1.20	142	180	1.26
South Africa	48	51	1.07	31	33	1.09
Other Africa	874	1,219	1.39	478	704	1.47
Rest of World	332	354	1.07	222	242	1.09
World	6,538	7,691	1.18	4,208	5,039	1.20

million

3.2.2 GDP

1) Overview

- Regional GDP is estimated by the Socio-economic Macro Frame model.
- The Socio-Economic Macro Frame model is a supply-side model, which estimates GDP from fixed capital stock and labor force, and socio-economic macro indices are determined based on the estimated GDP. Outputs of this model are GDP, final consumption, gross capital formation, sector-wise value added such as agriculture, industry and service sector, etc. These economic values are in US$ at constant year 2000 prices.

2) Methodology and assumption

- Population from 16 to 64 year-old is used as an input data to this model. The data source of population changes and future prospects are based on UN (2007a) and Council for Economic Planning and Development (2007b) as described in section 3.2.1.
- GDP is determined by using data of labor force, fixed capital stock and Time trend as shown in Figure 4. The GDP is estimated based on the production function of Cobb-Douglas type as shown in equation (18).

$$GDP_{i,\,t} = \alpha_i e^{\beta_i \cdot TIME_t} K_{i,t}^{\ \gamma_i} L_{i,t}^{\ 1-\gamma_i} \qquad (18)$$

Where,
i: region
t: year
α, β, γ: parameters
K: fixed capital stock
L: labor force
TIME: time-trend variable

- Fixed capital stock in that period is estimated from fixed capital stock in the previous year *t*-1, gross capital formation and depletion of fixed capital in the year *t*. Gross capital formation is estimated from GDP. And depletion of fixed capital is estimated from fixed capital stock in the previous year *t*-1 and depletion rate.
- Based on the estimated GDP, shares of primary, secondary and tertiary industries are calculated, and final consumption and sector-wise value added of primary, secondary and tertiary industries are estimated.

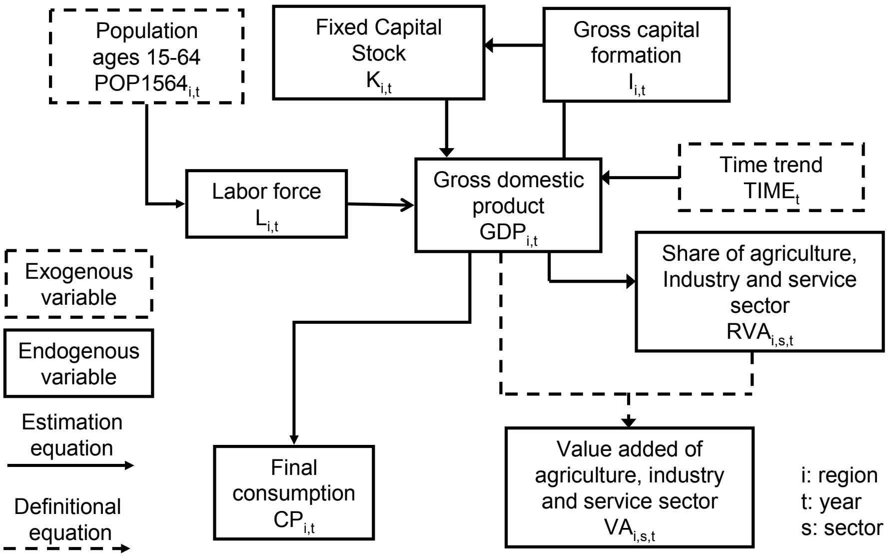


Figure 4 Structure of the Socio-economic Macro Frame model

3) Results in 23 regions

・ Table 6 shows the estimated GDP in 23 regions.

Table 6 Estimated GDP in 23 regions

	GDP per Capita			GDP		
	2005	2020	2020/2005	2005	2020	2020/2005
	[thousand US$][1)]			[billion US$][1)]		
Japan	38.8	48.2	1.2	4,960	5,994	1.2
China	1.5	4.6	3.0	2,024	6,540	3.2
India	0.5	1.3	2.4	611	1,767	2.9
Indonesia	0.9	1.5	1.7	203	403	2.0
Korea	12.1	22.1	1.8	577	1,088	1.9
Thailand	2.4	4.6	1.9	151	311	2.1
Other South-east Asia	1.4	2.6	1.8	383	860	2.2
Other South Asia	0.5	0.8	1.5	189	376	2.0
Middle East	4.1	6.3	1.5	785	1,599	2.0
Australia	22.8	31.0	1.4	463	725	1.6
New Zealand	15.2	20.1	1.3	62	93	1.5
Canada	25.3	31.2	1.2	815	1,142	1.4
United States	36.2	42.3	1.2	10,868	14,496	1.3
EU15 in Western EU	22.5	28.6	1.3	8,690	11,404	1.3
EU10 in Eastern EU	5.5	8.1	1.5	405	583	1.4
Russia	2.3	5.1	2.2	328	677	2.1
Mexico	6.0	10.2	1.7	622	1,230	2.0
Argentine	7.9	10.6	1.3	308	471	1.5
Brazil	3.5	5.7	1.6	663	1,251	1.9
Other Latin America	2.8	4.1	1.5	633	1,127	1.8
South Africa	3.3	4.9	1.5	156	251	1.6
Other Africa	0.7	1.0	1.5	568	1,205	2.1
Rest of World	4.0	6.1	1.5	1,317	2,144	1.6
World	5.5	7.2	1.3	35,782	55,738	1.6

1) Constant year 2000 prices

3.2.3 Energy prices

1) Overview

- Current domestic and international energy prices are based on Energy Prices and Taxes (IEA, 2007b). Future international energy prices are based on assumptions made by the Institute of Energy Economics, Japan (personal communication, 2009), that lie between the estimates in World Energy Outlook 2007 (IEA, 2007a) and World Energy Outlook 2008 (IEA, 2008).

2) Methodology and assumption

- International energy prices in the current and future years are based on assumptions made by the Institute of Energy Economics, Japan (IEEJ). As for future international energy prices, the IEEJ has estimated the 2020 and 2030 energy prices for coal, crude oil and natural gas. Those estimates lie about half-way between the estimates in World Energy Outlook 2007 (IEA, 2007a) and World Energy Outlook 2008 (IEA, 2008).

Table 7 Future energy prices

		Unit (real price)	2007	2020	2030
Crude oil		$/barrel	69.3	90	100
Gas	US	$/MBtu	6.8	11.2	13.5
	EU	$/MBtu	7.0	12.5	15.4
	Japan	$/MBtu	7.8	16.3	21.1
Coal		$/tonne	72.8	102.2	107.8

- Domestic energy prices in current year are set based on Energy Prices and Taxes (IEA, 2007b). IEA (2007b) shows the latest value in 2006, however, there is lack of data in some countries. In such a case, energy price data are substituted by the data of the surrounding countries or the average value among OECD countries.
- Future energy prices in each country and region are set under the assumption that domestic energy prices will rise according to the increase in international energy prices.

Table 8 Sector-wise energy prices in 23 regions

			JPN	CHN	IND	IDN	KOR	THA	XSE	XSA	XME	AUS	NZL	CAN
Industry	2000	Coal	0.07	0.04	0.05	0.03	0.08	0.05	0.05	0.05	0.04	0.07	0.07	0.07
		Oil	0.23	0.15	0.29	0.05	0.30	0.24	0.24	0.29	0.08	0.21	0.27	0.19
		Gas	0.50	0.18	0.13	0.05	0.38	0.13	0.13	0.13	0.03	0.15	0.07	0.10
		Electricity	1.67	0.71	0.93	0.42	0.60	0.66	0.66	0.93	0.64	0.53	0.33	0.45
	2006	Coal	0.10	0.06	0.07	0.05	0.13	0.08	0.08	0.07	0.06	0.10	0.10	0.10
		Oil	0.47	0.34	0.59	0.10	0.59	0.50	0.50	0.59	0.18	0.48	0.44	0.35
		Gas	0.48	0.37	0.26	0.10	0.55	0.26	0.26	0.26	0.06	0.31	0.21	0.30
		Electricity	1.40	0.66	1.18	0.53	0.76	0.83	0.83	1.18	0.80	0.66	0.71	0.55
	2020	Coal	0.14	0.10	0.11	0.09	0.17	0.12	0.12	0.11	0.10	0.14	0.14	0.14
		Oil	0.63	0.50	0.74	0.26	0.75	0.65	0.65	0.74	0.33	0.64	0.60	0.50
		Gas	0.81	0.58	0.47	0.31	0.76	0.47	0.47	0.47	0.27	0.48	0.38	0.47
		Electricity	1.63	0.77	1.19	0.85	0.81	1.05	1.03	1.03	1.42	1.03	0.75	0.71
Electricity plants	2000	Coal	0.05	0.04	0.03	0.03	0.08	0.05	0.05	0.03	0.05	0.05	0.05	0.03
		Oil	0.19	0.15	0.29	0.05	0.30	0.24	0.24	0.29	0.08	0.21	0.27	0.13
		Gas	0.19	0.18	0.13	0.05	0.33	0.13	0.13	0.13	0.04	0.15	0.07	0.15
	2006	Coal	0.10	0.06	0.05	0.04	0.08	0.07	0.07	0.05	0.07	0.07	0.07	0.04
		Oil	0.44	0.34	0.59	0.10	0.64	0.51	0.51	0.59	0.18	0.48	0.60	0.28
		Gas	0.28	0.37	0.26	0.10	0.53	0.26	0.26	0.26	0.08	0.31	0.13	0.31
	2020	Coal	0.14	0.10	0.09	0.08	0.12	0.11	0.11	0.09	0.11	0.11	0.11	0.08
		Oil	0.60	0.50	0.74	0.26	0.80	0.67	0.67	0.74	0.33	0.64	0.76	0.44
		Gas	0.61	0.58	0.47	0.31	0.74	0.47	0.47	0.47	0.29	0.48	0.30	0.48
Residential	2000	Coal	0.20	0.07	0.14	0.14	0.20	0.14	0.14	0.14	0.14	0.20	0.20	0.20
		Oil	0.53	0.28	0.28	0.04	0.70	0.46	0.46	0.28	0.24	0.47	0.47	0.30
		Gas	1.44	0.44	0.28	0.02	0.50	0.28	0.28	0.28	0.13	0.37	0.40	0.22
		Electricity	2.49	0.94	0.38	0.29	0.97	0.70	0.70	0.38	0.56	0.73	0.70	0.62
	2006	Coal	0.28	0.11	0.19	0.19	0.28	0.19	0.19	0.19	0.19	0.28	0.28	0.28
		Oil	0.83	0.52	0.52	0.08	1.39	0.91	0.91	0.52	0.51	0.88	0.88	0.84
		Gas	1.38	0.43	0.49	0.03	0.71	0.49	0.49	0.49	0.22	0.66	0.86	0.54
		Electricity	2.20	0.89	0.46	0.35	1.14	0.84	0.84	0.46	0.67	0.89	1.54	0.73
	2020	Coal	0.32	0.15	0.23	0.23	0.32	0.23	0.23	0.23	0.23	0.32	0.32	0.32
		Oil	0.98	0.67	0.67	0.24	1.54	1.07	1.07	0.67	0.67	1.04	1.04	1.00
		Gas	1.70	0.64	0.70	0.24	0.92	0.70	0.70	0.70	0.44	0.83	1.04	0.71
		Electricity	2.43	1.01	0.48	0.66	1.20	1.06	1.04	0.32	1.29	1.25	1.58	0.89
Transportation	2000	Oil	1.15	0.38	0.84	0.15	1.54	0.48	0.48	0.84	0.18	0.61	0.64	0.59
	2006	Oil	1.42	0.67	1.22	0.59	2.19	0.94	0.94	1.22	0.25	1.12	1.32	1.03
	2020	Oil	1.57	0.83	1.38	0.75	2.35	1.10	1.10	1.38	0.40	1.28	1.48	1.19

			USA	XE15	XE10	RUS	MEX	ARG	BRA	XLM	ZAF	XAF	XRW
Industry	2000	Coal	0.05	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.02	0.02	0.07
		Oil	0.17	0.18	0.12	0.11	0.17	0.17	0.17	0.17	0.21	0.21	0.17
		Gas	0.19	0.18	0.15	0.03	0.13	0.13	0.13	0.13	0.26	0.26	0.33
		Electricity	0.53	0.42	0.43	0.15	0.59	0.59	0.59	0.59	0.20	0.20	0.71
	2006	Coal	0.09	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.04	0.04	0.10
		Oil	0.35	0.37	0.31	0.24	0.35	0.35	0.35	0.35	0.48	0.48	0.36
		Gas	0.33	0.36	0.33	0.07	0.25	0.25	0.25	0.25	0.36	0.36	0.46
		Electricity	0.70	0.59	0.85	0.28	1.15	1.15	1.15	1.15	0.25	0.25	0.66
	2020	Coal	0.13	0.14	0.15	0.15	0.14	0.14	0.14	0.14	0.08	0.08	0.14
		Oil	0.50	0.53	0.47	0.40	0.51	0.51	0.51	0.51	0.64	0.64	0.52
		Gas	0.51	0.58	0.54	0.28	0.42	0.42	0.42	0.42	0.57	0.57	0.67
		Electricity	0.86	0.79	1.29	0.51	1.46	1.27	1.54	1.16	0.42	0.42	0.91
Electricity plants	2000	Coal	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.01	0.01	0.05
		Oil	0.18	0.18	0.12	0.11	0.17	0.17	0.17	0.17	0.21	0.21	0.17
		Gas	0.19	0.18	0.15	0.03	0.13	0.13	0.13	0.13	0.26	0.26	0.27
	2006	Coal	0.06	0.09	0.10	0.10	0.09	0.09	0.09	0.09	0.02	0.02	0.07
		Oil	0.34	0.39	0.31	0.26	0.35	0.35	0.35	0.35	0.48	0.48	0.37
		Gas	0.31	0.36	0.30	0.07	0.25	0.25	0.25	0.25	0.54	0.54	0.39
	2020	Coal	0.10	0.13	0.14	0.14	0.13	0.13	0.13	0.13	0.06	0.06	0.11
		Oil	0.49	0.55	0.47	0.42	0.51	0.51	0.51	0.51	0.64	0.64	0.53
		Gas	0.48	0.58	0.52	0.28	0.42	0.42	0.42	0.42	0.75	0.75	0.60
Residential	2000	Coal	0.20	0.20	0.15	0.15	0.20	0.20	0.20	0.20	0.02	0.02	0.03
		Oil	0.40	0.50	0.45	0.24	0.47	0.47	0.47	0.47	0.24	0.24	0.24
		Gas	0.36	0.39	0.27	0.01	0.20	0.28	0.28	0.28	0.57	0.57	0.44
		Electricity	0.95	1.18	0.76	0.31	0.79	0.79	0.79	0.79	0.46	0.46	0.94
	2006	Coal	0.28	0.28	0.26	0.26	0.28	0.28	0.28	0.28	0.03	0.03	0.05
		Oil	0.72	0.95	1.01	0.51	0.88	0.88	0.88	0.88	0.45	0.45	0.51
		Gas	0.59	0.79	0.62	0.02	0.35	0.46	0.46	0.46	0.68	0.68	0.43
		Electricity	1.21	1.67	1.54	0.42	1.17	1.17	1.17	1.17	0.69	0.69	0.89
	2020	Coal	0.32	0.32	0.30	0.30	0.32	0.32	0.32	0.32	0.07	0.07	0.09
		Oil	0.88	1.11	1.16	0.67	1.04	1.04	1.04	1.04	0.61	0.61	0.67
		Gas	0.76	1.00	0.83	0.23	0.52	0.63	0.63	0.63	0.89	0.89	0.64
		Electricity	1.36	1.88	1.97	0.65	1.48	1.29	1.56	1.18	0.86	0.86	1.15
Transportation	2000	Oil	0.47	1.24	0.92	0.30	0.68	1.02	1.02	1.02	0.55	0.55	0.65
	2006	Oil	0.81	1.92	1.64	0.67	0.78	1.44	1.44	1.44	1.12	1.12	0.92
	2020	Oil	0.97	2.08	1.80	0.82	0.94	1.60	1.60	1.60	1.28	1.28	1.07

Unit: US$/kgoe

3.3 Composition of power sources

3.3.1 Fossil fuels

- In this study's baseline case for 2020, the composition of coal, oil, gas, nuclear, hydro, wind, solar, biomass, and geothermal power refers to the regional compositions of energy types given in the reference scenario in World Energy Outlook (IEA, 2007a).
- Nuclear, hydro and geothermal power are not considered as mitigation options in this study. Thus, the amount of power generation of nuclear, hydro and geothermal power is set at the same level as the baseline scenario, in all cases of carbon prices. Even if electricity demands decrease due to the effects of mitigation measures in the demand side, the amount of nuclear, hydro and geothermal power generation does not change and only the composition of fossil fuels and renewable energy changes.
- In the countermeasure case, mitigation options are considered for the end-use side by examining two different cases for the supply side and estimating CO_2 emissions from the balance of electricity demand in end-use technologies and energy supply from power generation.

Table 9 Composition of fossil fuels

Case	Composition of fuel types
Energy security case	In reality, the composition of fossil fuel energy types is not flexible, even in 2020, due to social barriers, such as energy security and costs and technological restrictions. Thus, shifts in energy from coal and oil power plants to efficient gas power plants or renewables are restricted to a certain amount. For example, new gas power plants are introduced only when existing coal and oil power plants are retired or an additional power plant is needed to meet increased energy demand.
Optimization case	No restriction or barrier exists, and the composition of fossil fuel energy types is freely determined by total-cost optimization. Thus, if a shift in energy from coal and oil power plants to efficient gas power plants provides a cost benefit even before the coal and oil power plants are retired, then the existing coal and oil power plants will be immediately stopped and replaced by new gas power plants.

3.3.2 Renewable energy

- According to the estimations of renewable energy of solar, wind and biomass, there are large technological potentials in the global scale. However, there may be some social barriers, technological restrictions and grid-access issues depending on regions. Thus in this study, the maximum limit of the ratio of the total renewable energy of solar, wind and biomass is set at 20 % of the total energy supply in each region and country.

3.3.2.1 Solar photovoltaics

- The global potential of solar energy is estimated as follows using a grid cell approach based on GIS (Geographic Information System) data.
  - First, the monthly and hourly solar elevation and the solar azimuth angle in 3×3

arc-minute grid cells are calculated.

- The monthly and hourly insolation intensities on a horizontal surface are calculated using GIS data for average insolation.
- The shade of landform is estimated in each grid cell by considering elevation, solar elevation, and solar azimuth angle.
- The monthly and hourly insolation intensities at optimum tilt are calculated.
- Areas available for the installation of solar-PVs are estimated based on GIS data for land cover types and the area-ratio of available insolation for each land cover type.
- Finally, the technical potentials of solar energy are estimated by considering the monthly and hourly insolation intensities at optimum tilt, the available area for solar-PV, and the efficiency of the PV module.
- This potential is divided into several grades according to the annual insolation incident at optimum tilt. The data for the grid cells is aggregated to obtain the potential for regions and countries.

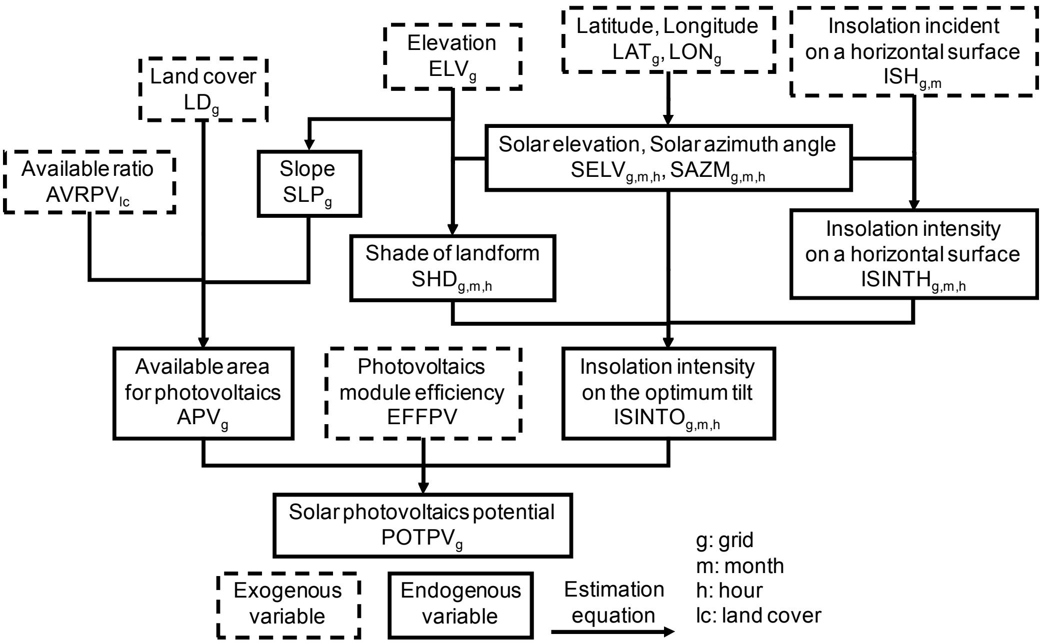


Figure 5 Structure of the Solar Photovoltaics Potential model

3.3.2.2 Onshore wind

- The global potentials of onshore wind energy are estimated as follows using a grid cell approach based on GIS data.
  - First, the monthly and hourly wind speeds in 3×3 arc-minute grid cells are calculated.
  - Areas available for the installation of windmills are estimated based on GIS data for land cover types, the area-ratio of available wind in each land cover type, the slope, and the elevation.
  - The number of windmills available for wind energy production are estimated based on a standard windmill with a rated power output of 2 MW.

- The frequency distribution of each wind speed level at a given windmill hub height is estimated using the Rayleigh distribution method and the Power Law for wind shear. The estimation is based on GIS data for the monthly average wind speed at a height of 50 m above the surface.
- Finally, the technical potential for onshore wind energy is estimated by considering the energy output curve of a windmill, the wind speed frequency distribution, the number of available windmills, the output correction, and other losses.
- This potential is divided into several grades according to the annual utilized capacity of windmills. The data for the grid cells is aggregated to obtain the potential for regions and countries.

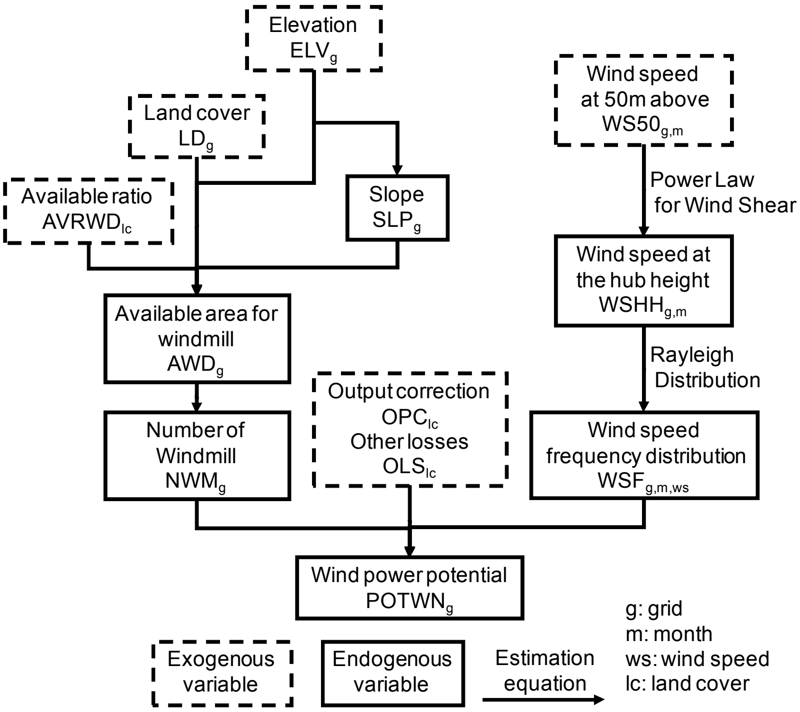


Figure 6 Structure of the Wind Power Potential model

3.3.2.3 Biomass

・ For biomass energy, the potentials of residual biomass are estimated as follows:
  - In this study, residual biomass is classified into 11 categories: 1) industrial roundwood residues, 2) black liquor, 3) mill residues, 4) paper scrap, 5) timber scrap, 6) crop residues, 7) sugarcane residues, 8) bagasse, 9) dung, 10) kitchen refuse, and 11) human feces. Crop residues and sugarcane residues are used in the transportation sector, and other residual biomass is used for biomass power generation.
  - The technological potentials of residual biomass for power generation in 2020 are estimated from the amount of available residual biomass used in 2005.

3.4 Service demands

3.4.1 Industry

3.4.1.1 Iron and steel

1) Overview

- Volume of global trade of iron and steel in the iron and steel sector accounts for approximately 42 % of the global iron and steel production in 2004 (IISI, 2006a). Thus, in order to estimate iron and steel production in each country, it is necessary to consider not only domestic demands but also volume of international trade. In this study, iron and steel production is estimated by the Steel Production and Trade model, which includes global trade across regions.
- The Steel Production and Trade model is a partial equilibrium model which considers iron and steel price and the balances of domestic and international iron and steel demand and supply. Regional production and volume of import and export are determined at the equilibrium point.
- Data settings of GDP and population are the same as described in sections 3.2.1 and 3.2.2.

2) Methodology and assumption

- The structure of the Steel Production and Trade model is shown in Figure 7.
- Per capita consumption of iron and steel is estimated by per capita GDP in each country and region. Then the total consumption is estimated by multiplication with the population in each country and region.
- Iron and steel production is dependent upon the producer price. The higher the price, the more products the producer makes.
- Export amount by country and region is determined by multiplying domestic production with export ration (i.e. percentage of export volume in the total production in a certain country and region). And export ration depends on the relation between domestic price and international price. Thus, export amount depends on domestic production, domestic and international prices. By the same token, import amount also depends on domestic consumption, and domestic and international prices.
- The volume of production, export and import in each country and region is affected by the level of domestic and international prices. Each volume and price is determined at the equilibrium point to meet the balance of domestic and international market.

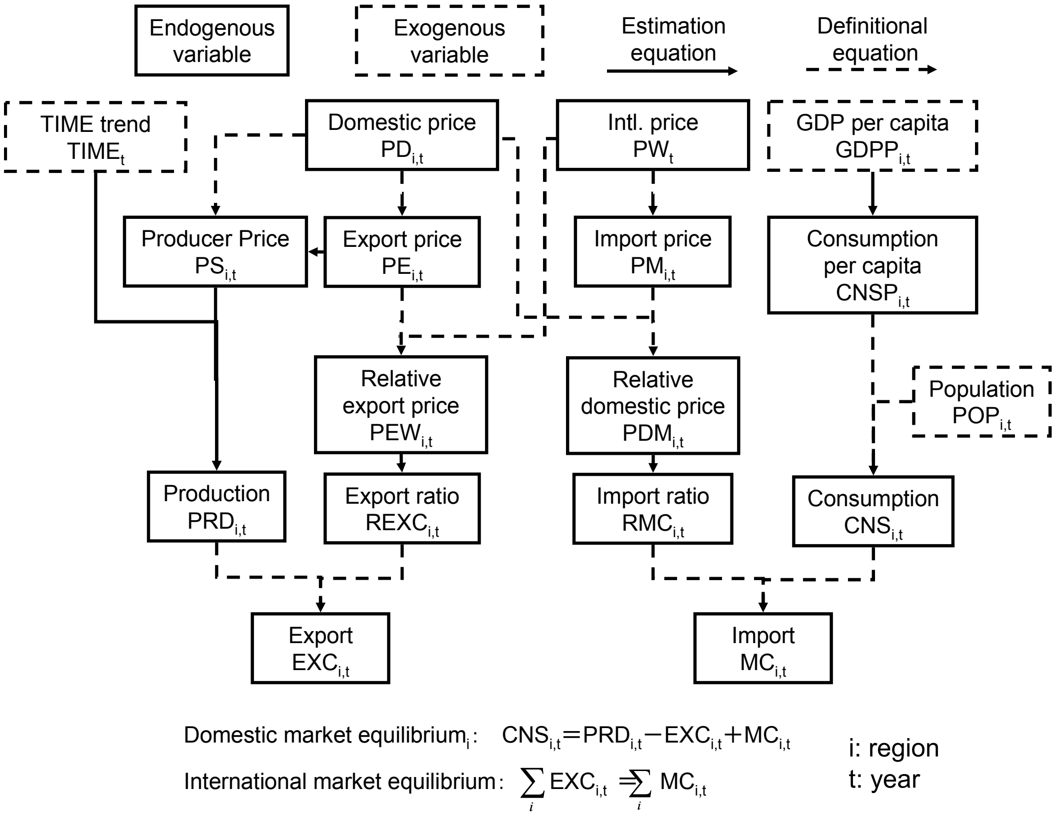


Figure 7　Structure of the Steel Production and Trade model

3) Results in 23 regions

- Figure 8 shows estimated production of crude steel in 23 regions.

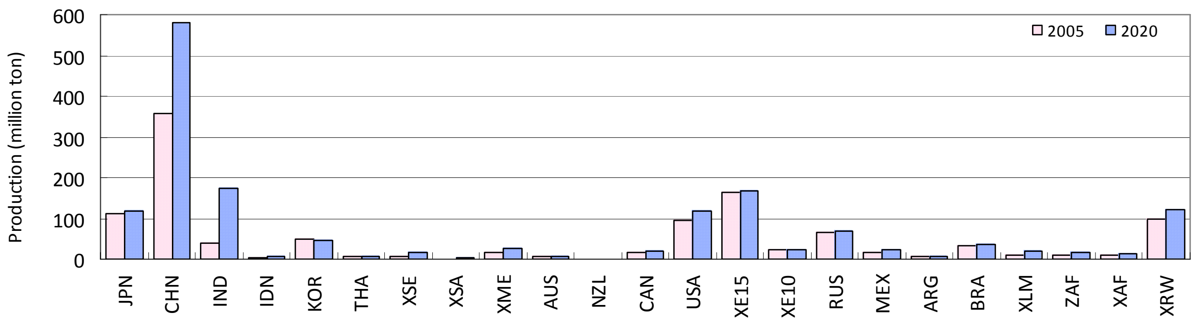


Figure 8 Estimated production of crude steel in 23 regions

3.4.1.2 Cement

1) Overview

- Volume of global trade in the cement sector accounts for approximately 4.3 ~ 8.6 % of the global cement production from 1971 to 2005. As the share of global trade in the total global production is small, in this study cement production is estimated under the framework of domestic production and consumption and it does not take global trade into account.
- By using the Cement Production model, domestic cement production is estimated in each country and region. Data settings of GDP and population are the same as described in sections 3.2.1 and 3.2.2.

2) Methodology and assumption

- Per capita consumption of cement is estimated by per capita GDP in each country and region. Then the total consumption is estimated by multiplication with the population as shown in Figure 9.
- Cement production is determined using equation (19). This equation is based on the assumption that, as per capita GDP increases to large levels, growth rate of per capita cement production decreases and per capita production reaches asymptotically to a certain saturation level.

$$\ln\left(PRDP_{i,t}\right) = \frac{\alpha_i}{1+\exp\left[-\beta\cdot\left\{\ln\left(GDPP\right)-\gamma_i\right\}\right]} \tag{19}$$

Where,
i: region
t: year
α, β, γ: parameters
GDPP: per capita GDP
PRDP: per capita production

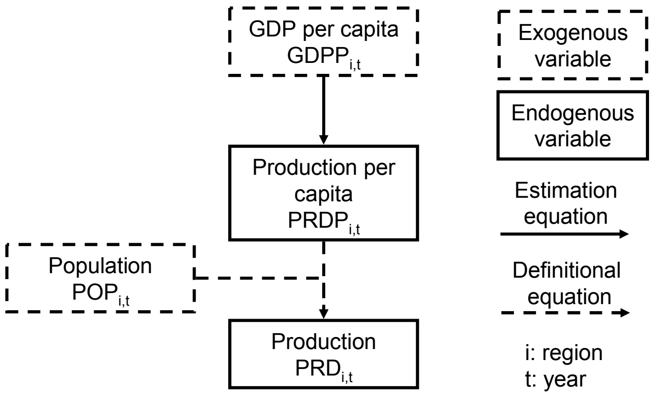


Figure 9 Structure of the Cement Production model

3) Results in 23 regions

-
- Figure 10 shows estimated cement production in 23 regions.

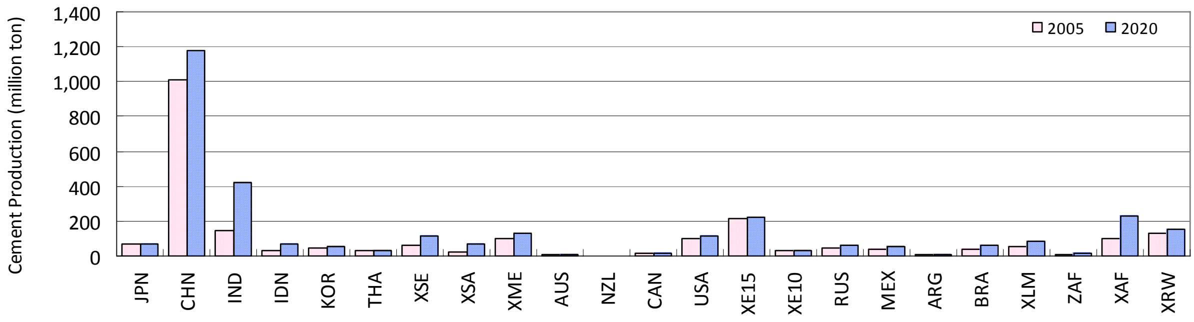


Figure 10 Estimated production of cement in 23 regions

3.4.1.3 Other industry

1) Overview

- In case of other industry category in the industry sector in this study, it is difficult to specify a tangible energy-service demand of a certain single product. Thus, value added in secondary industry is used as a representative index to explain energy-service demands in other industry.
- Data settings of GDP and population are the same as described in sections 3.2.1 and 3.2.2.

2) Methodology and assumption

- Using the same methodology as described in section 3.2.2, value added in secondary industry is estimated by the Socio-Economic Macro frame model.

3) Results in 23 regions

- Figure 11 shows estimated value added in secondary industry in 23 regions.

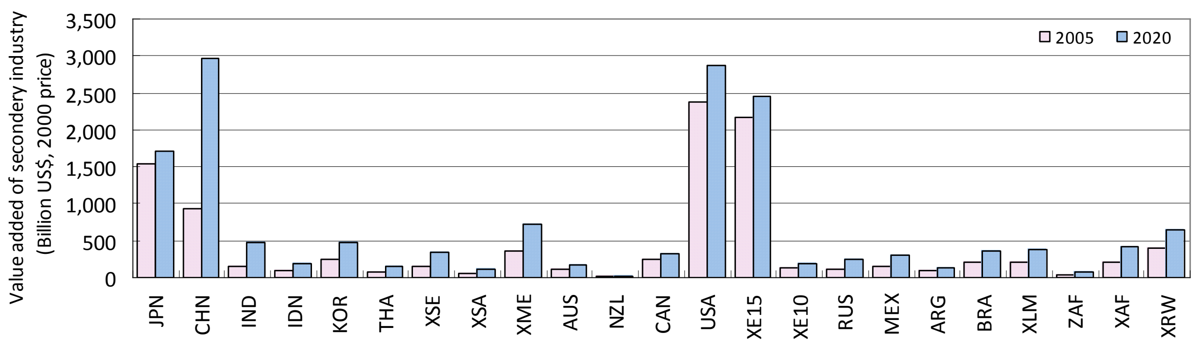


Figure 11 Estimated value added in secondary industry in 23 regions

3.4.2 Transport

3.4.2.1 Passenger transport

1) Overview

- Transportation volumes of passenger car, bus, passenger rail, and domestic and international aircraft are estimated by the Passenger Transportation Demand model, in the unit of passenger-km.
- The Passenger Transportation Demand model estimates transportation volumes for different transportation modes based on the input data of population and per capita GDP. Total passenger transportation volumes are first estimated and transportation volumes in each transportation mode are estimated by multiplying with transport share.
- Data settings of GDP and population are the same as described in sections 3.2.1 and 3.2.2.

2) Methodology and assumption

- Figure 12 shows structure of the Passenger Transportation Demand model.

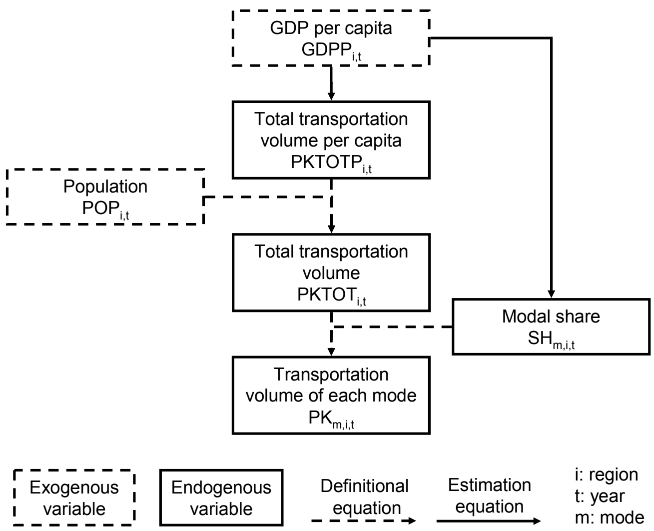


Figure 12 Structure of the Passenger Transportation Demand model

- Total passenger transportation volume per capita is estimated by per capita GDP in each country and region. Total passenger transportation volume per capita is estimated by equation (20) which uses the logistic function of S-shaped curve.

$$PKTOTP_{i,t} = \frac{\alpha_i}{1+\exp\left\{-\beta\cdot\left(GDPP_{i,t}-\gamma_i\right)\right\}} \tag{20}$$

Where,

i: region

t: year

α, β, γ: parameters
GDPP: per capita GDP
PKTOTP: total passenger transportation volume per capita

- Total passenger transportation volumes are estimated by multiplying population with total transportation volume per capita.
- The transport share for each mode is formulated using the logit model shown in equation (21), which uses the natural log of per capita GDP as an explanatory variable.

$$SH_{m,i,t} = \frac{\exp\left\{\alpha_{m,i} + \beta_m \cdot \ln\left(GDPP_{i,t}\right)\right\}}{\sum_{m'} \exp\left\{\alpha_{m',i} + \beta_{m'} \cdot \ln\left(GDPP_{i,t}\right)\right\}} \tag{21}$$

Where,
m: mode (car, bus, rail, domestic aircraft and international aircraft)
α, β: parameters
SH: transport share of each mode

- Transportation volumes for different transportation modes are determined by multiplying total transportation volumes with transport share.

3) Results in 23 regions
- Figure 13 shows estimated transportation volume by passenger car in 23 regions.

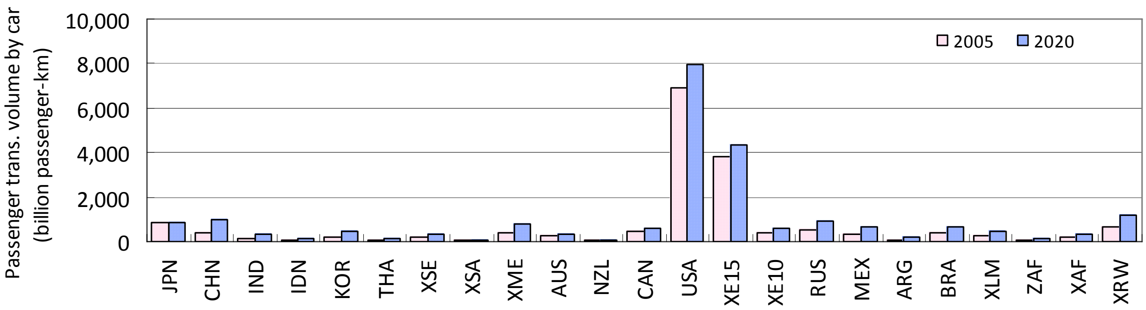


Figure 13. Estimated total passenger transportation volumes in 23 regions

3.4.2.2 Freight transport

1) Overview
- Freight transportation volumes of truck, rail, and domestic and international shipping are estimated by the Freight Transportation Demand model. For truck and freight rail, the unit of transportation volume is taken as ton-km. But for domestic and international shipping, there is no reliable dataset, hence the unit of energy consumption is used as an alternative indicator.
- The Freight Transportation Demand model estimates transportation volumes for different transportation modes based on the input data of population and GDP. For land transportation modes such as truck and freight rail, total freight transportation volumes

are first estimated and transportation volumes in each transportation mode are estimated by multiplying with respective transport shares. For domestic and international shipping, transportation volumes are estimated individually.

- Data settings of GDP and population are the same as described in sections 3.2.1 and 3.2.2.

2) Methodology and assumption

- Figure 14 shows structure of Freight Transportation Demand model.

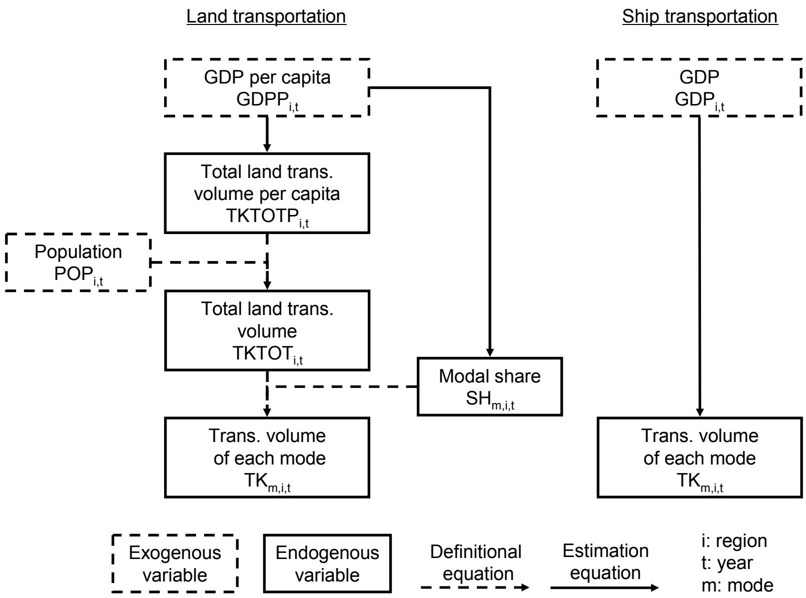


Figure 14 Structure of Freight Transportation Demand model

- For truck and freight rail, total freight transportation volume per capita is estimated by per capita GDP in each country and region. The total freight transportation volume per capita is estimated by equation (22) which uses the logistic function of S-shaped curve.

$$TKTOTP_{i,t} = \frac{\alpha_i}{1+\exp\left\{-\beta \cdot \left(GDPP_{i,t} - \gamma_i\right)\right\}} \tag{22}$$

Where,
i: region
t: year
α, β, γ: parameters
GDPP: per capita GDP
TKTOTP: total freight transportation volume per capita

- Total freight transportation volumes are estimated by multiplying population with total transportation volume per capita.
- The transport share for each mode is formulated using the logit model shown in equation (23), which uses the natural log of per capita GDP as an explanatory variable.

$$SH_{m,i,t} = \frac{\exp\left\{\alpha_{m,i} + \beta_m \cdot \ln\left(GDPP_{i,t}\right)\right\}}{\sum_{m'} \exp\left\{\alpha_{m',i} + \beta_{m'} \cdot \ln\left(GDPP_{i,t}\right)\right\}} \quad (23)$$

Where,
m: mode
α, β: parameters
SH: transport share of each mode

- Transportation volumes for different transportation modes are determined by multiplying net transportation volumes with transport share as shown in Figure 14.
- For domestic and international shipping, freight transportation volumes are estimated directly by GDP as follows

$$TK_{r,m,t} = \alpha_{r,m} \cdot GDP^{\beta_{r,m}} \quad (24)$$

3) Results in 23 regions
- Figure 15 shows estimated freight transportation volume by truck in 23 regions.

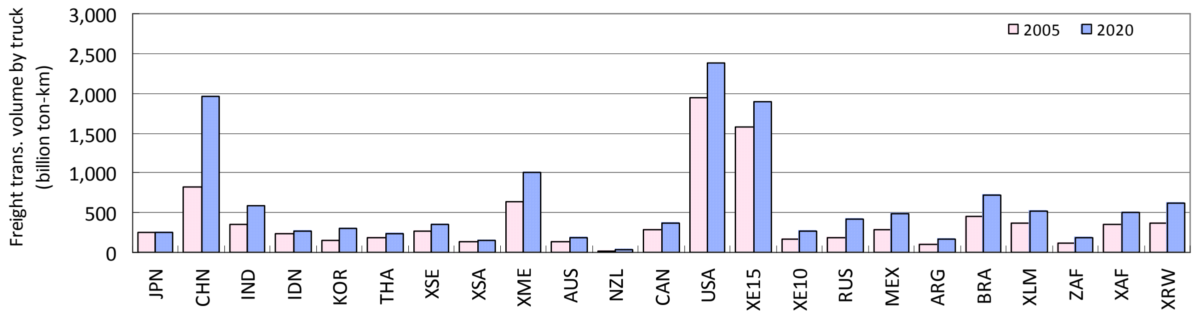


Figure 15 Estimated freight transportation volume by truck in 23 regions

3.4.3 Residential and commercial

1) Overview
- In residential and commercial sector, target energy services and energy types are set as follows:
  - －Energy type: coal, biomass, natural gas, kerosene, LPG, geothermal, solar (including solar heat and solar light), electricity, and heat.
  - －Energy service type: warming, cooling, hot water, cooking, lighting, refrigerator, TV(only for residential sector), and others.
- Energy demands in this study are defined as equation (25), which explains the relation between total energy consumption and energy consumption per unit in the unit of ton of oil equivalent (toe).

$$Energy\ demands\ of\ service\ type\ i = \frac{Energy\ consumption}{Energy\ consumption\ per\ unit\ of\ energy\ service\ i} \quad (25)$$

2) Methodology and assumption

・ While energy service demand should be estimated from the key factor that has an impact (driving force), driving force data by region is difficult to obtain. Therefore, we use a simple methodology to estimate future energy service demand. Figure 16 is an outline of the methodology.

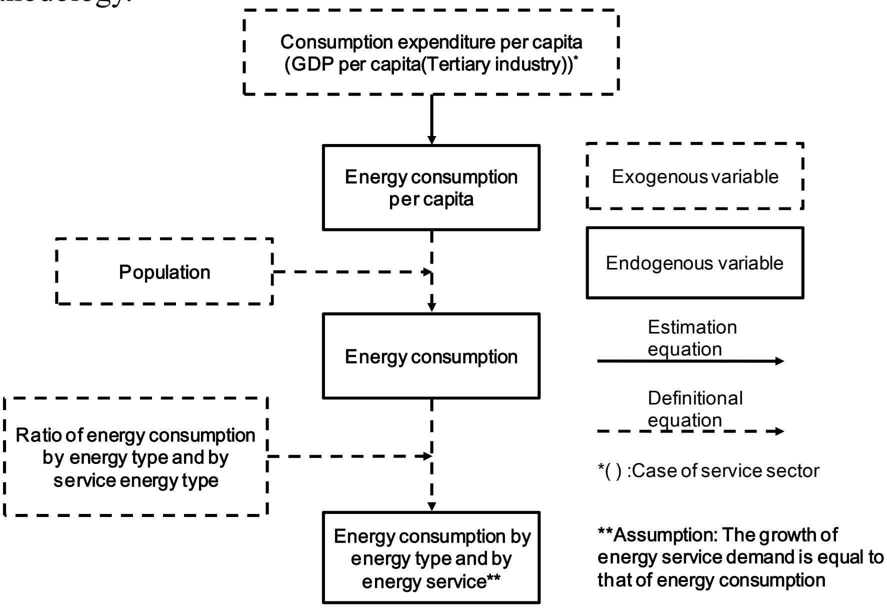


Figure 16 Outleine of methodology

a) Data for past energy consumption

・ Energy consumption by region, by sector, by energy type and by service type in the base year is based on the data of IEA Energy Balance Table (IEA, 2007c, 2007d). However, in the Energy Balance Table, the category named “other sector” includes data of residential, commercial, agriculture, fishing, and non-specified sectors. In this study, these non-specified data are disaggregated into certain sectors based on the methodology by OECD development center(1998) and the Energy Balances are adjusted in the base year 2005.

b) Estimation of future energy consumption

・ The energy consumption in 2020 by sector is estimated based on the time-series data, and the ratio of energy consumption by energy type and by service type is set based on SAGE (USDOE, 2003) and World Energy Outlook (IEA, 2007a). Then energy consumption by region, by sector, by energy type and by service type in 2020 is estimated by these data sets. For estimation of energy consumption by sector, various parameters are determined based on the regression analysis method using time series data of GDP and population from 1971 to 2005.

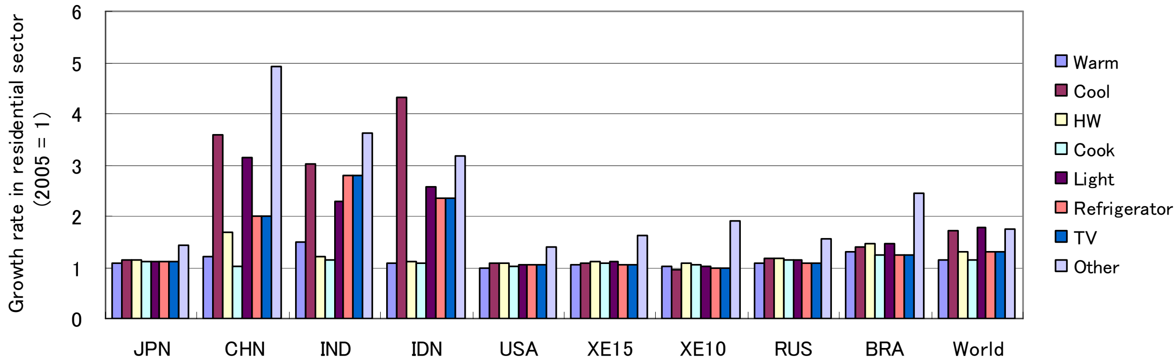
・ Due to regional economic growth, characteristics of energy use in 2020 will be different from the current situation, especially in the developing countries. For example, people in the developing countries are likely to use more electricity and less traditional biomass. Thus, in this study, ratio of energy consumption by energy service is set by considering several data sources such as SAGE (USDOE, 2003) and World Energy Outlook (IEA, 2007a).

c) Future energy service demand

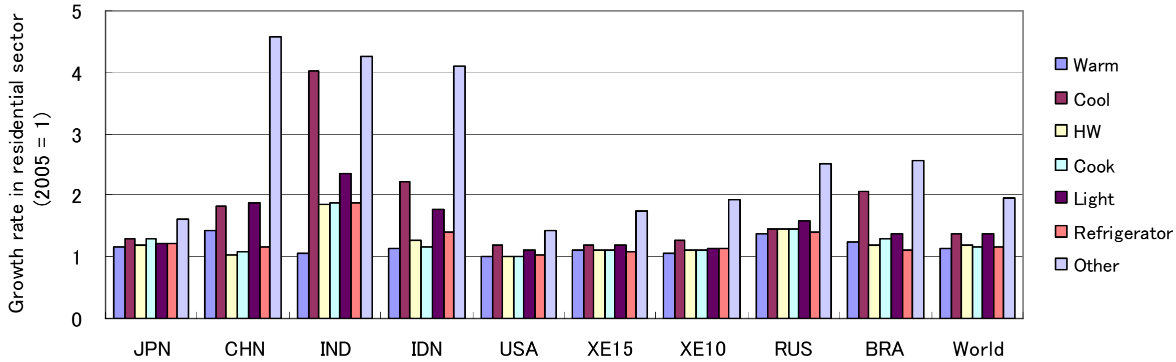
- We define the growth of energy consumption as equal to the growth of energy service demand.

3) Results in 23 regions

- Energy consumption by region, by sector, by energy type and by service type in 2020 is estimated, and Figure 17 shows growth rate of energy consumption by service type in residential and commercial sector in some major countries in 2020, as compared to the baseline in 2005. It can be seen that growth rates in developing countries are larger than in developed countries.



(a) Residential sector



(b) Commercial sector

Figure 17 Growth rate of energy service by service type in some major countries in 2020 (2005 =1)

3.4.4 Agriculture

3.4.4.1 Agriculture soil and rice cultivation

1) Overview

- Agricultural products are defined as service demand in rice cultivation and cropland sector. Target agricultural products are listed in Table 10.

Table 10 Target agricultural products in rice cultivation and cropland sector

Service	Source	Products		Target gas
Agricultural products	Cropland	Corn Bean	Wheat Cotton	N_2O
		Others (8 products)		
	Rice cultivation	Rice		N_2O, CH_4

- Agricultural products are estimated by the Agricultural Trade Model in this study, based on the input data such as population and GDP. The framework of the Agricultural Trade Model is based on the PEATSIM model (Abler, 2007) including international agricultural trade developed by the US Department of Agriculture. However, the PEATSIM model does not consider future population growth and impacts of income increase on food demands. The Agricultural Trade Model used in this study includes these aspects and considers 34 types of agricultural products such as beef, pork, chicken, rice, wheat, corn, beans, etc.

2) Methodology and assumption

- The Agricultural Trade Model is a recursive dynamic model. Domestic and international demand and supply of agricultural products is adjusted and determined by agricultural prices. After regional demand and supply is estimated, global demand and supply is balanced in order to fill the gap of demand and supply in each region at international agricultural prices in time period *t*. The international agricultural prices affect the regional agricultural prices, and subsequently the regional demand and supply in time period *t*+1 is estimated.
- Agricultural products are estimated based on the input data such as population and GDP. The Agricultural Trade Model consists of simultaneous equations considering production, supply and demand, stock, export and import, international trade prices, domestic price, and so on, and various parameters are fixed in order to meet the actual values reported by FAOSTAT (FAO, 2005), as shown in Figure 18.
- Agricultural products are estimated by multiplying cropland area by crop productivity. The results of estimated future cropland area of targeted agricultural products in this study are similar to those of FAO(2002) and Rosegrant, et a. (2001,2002). As for other cropland area which is out of scope in this study, firstly, a ratio of coverage of cropland area of this study is compared with the total cropland data in the regional landuse database of FAOSTAT (FAO, 2005) in the base year. Then, cropland area covered in this

study is set at the constant ratio of the total cropland coverage in the future. Thus the targeted cropland area and other cropland area are estimated.

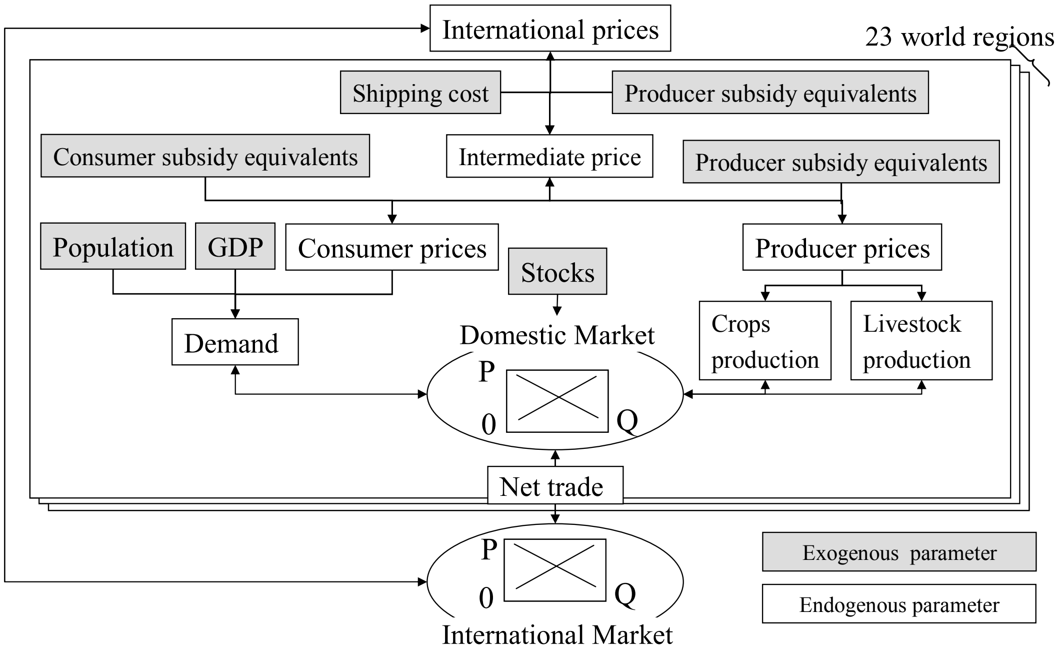


Figure 18 Structure of the agricultural trade model

3) Results in 23 regions

・ Figure 19 shows estimated agricultural production in 23 regions.

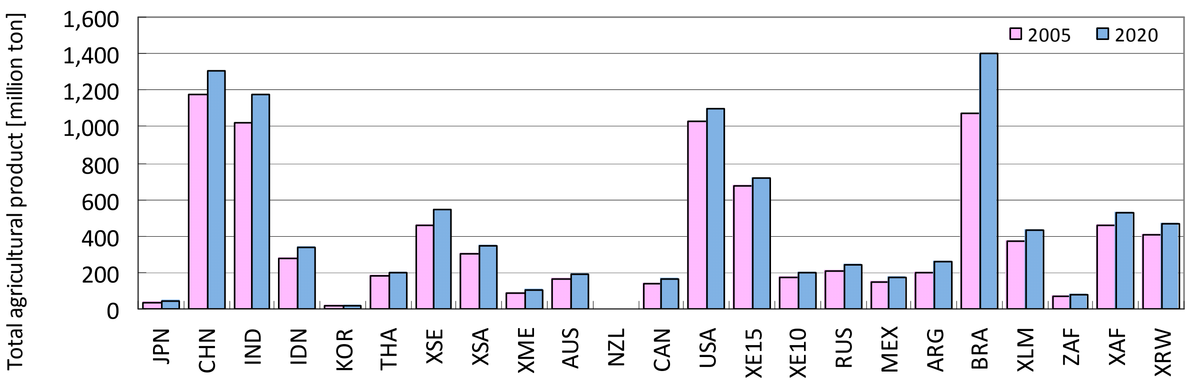


Figure 19 Estimated agricultural production in 23 regions

3.4.4.2 Manure management and enteric fermentation

1) Overview

- Livestock products are defined as service demand in manure management and livestock rumination sector. Target livestock products are listed in Table 11.

Table 11 Livestock products in manure management and livestock rumination sector

Service	Source	Products		Target gas
Livestock products	Manure management	Dairy cattle Beef cattle Sheep Camel Mule Swine Duck	Buffalo Goat Horse Donkey Chicken Turkey	N_2O, CH_4
	Livestock rumination			CH_4

- Livestock products are estimated by the same Agricultural Trade Model as the one described in section 3.4.4.1.

2) Methodology and assumption

- As described in section 3.4.4.1, future livestock products such as daily cattle, beef cattle, swine, chicken etc. are estimated using the Agricultural Trade Model. On the other hand, for livestock products which are not dealt within the Agricultural Trade Model such as buffalo, goat, sheep etc., growth rate of products is set based on the representative previous study by FAO(2002).
-

3) Results in 23 regions

- Figure 20 shows estimated livestock production in 23 regions.

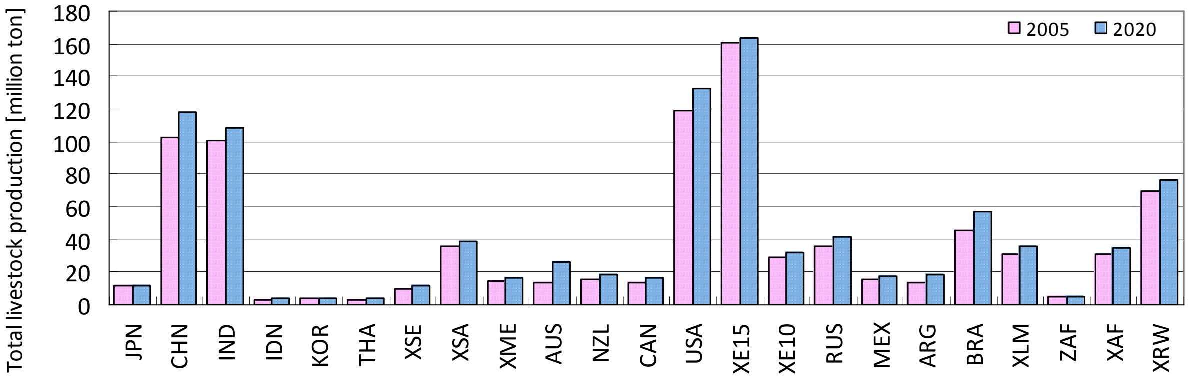


Figure 20 Estimated livestock production in 23 regions

3.4.5 Waste management

1) Overview

- Generated municipal solid waste is taken as a driver of CH_4 emission in the waste management sector (Table 12).
- This study covers only municipal solid waste management and does not include waste water management.

Table 12 Target waste and waste management measures

Driver	Source	Management measures	Target gas
Solid waste generation	Municipal solid waste	Landfill	CH_4
		Incineration Open burning Compost	N_2O, CH_4

2) Methodology and assumption

- Per capita municipal solid waste generation is estimated based on per capita GDP. There is a certain relationship between per capita municipal solid waste generation and per capita GDP. Parameters of correlation between these two variables are estimated by 304 data points including time series data from 1995 to 2003 in EU regions (EEA, 2005), the data in major 23 countries in 1996 and that in 69 countries in 2000 (IPCC, 2006a)[¥].
- Municipal solid waste generation is estimated by multiplying per capita municipal solid waste generation by the corresponding population, i.e. total population in developed countries (UN, 2007a) and urban population in developing countries (UN, 2005a). As for open burning, the corresponding population is the number of rural population.
- The types of municipal solid waste in each waste management measure are estimated based on the parameters defined by the IPCC Inventory Guideline (IPCC, 2006a).

3) Results in 23 regions

- Figure 21 shows estimated municipal solid waste generation per capita in 23 regions.

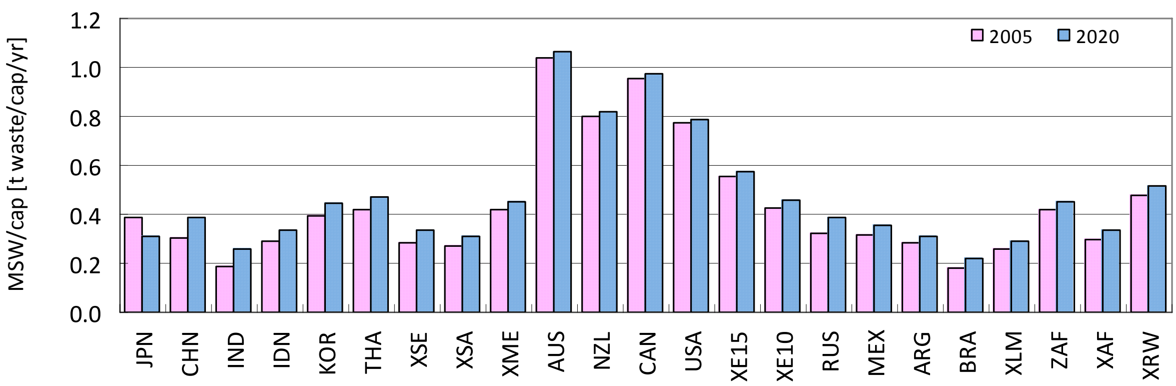


Figure 21 Estimated municipal solid waste generation per capita in 23 regions

3.4.6 Fugitive emissions from fuel production

1) Overview

- In coal mining, CH_4 is stored in a coal seam. During the process of coal mining operation, CH_4 is released into the atmosphere. CH_4 is emitted during mining, processing, transport, and storage, but the largest source of emission is the mining process. Deeper coal generally contains more CH_4 in a coal seam, thus it is necessary to distinguish between two different types of coal mining: underground coal mining and surface coal mining.
- In natural gas production, processing, transportation and storage, and distribution, natural gas is transported under high pressure. Thus the largest source of CH_4 emission is the leakage during the transportation process.
- In crude oil production, transportation, and refining in onshore or offshore oil plants, the largest source of CH_4 emission is fugitive emissions from the production process.

2) Methodology and assumption

- For coal mining, the underground mining and surface mining assumptions are set as follows. In Annex I countries, the ratio of underground to surface coal mining is based on the national GHG inventory reported by each country under the UNFCCC(2008). In non-Annex I countries, the ratio of underground to surface coal mining is based on the data source for WEC Survey of Energy Resources (WEC, 2007). However, it is important to note that no clear and international definitions exist for underground mining and surface mining. This study categorizes bituminous coal mining as underground mining and sub-bituminous & lignite coal mining as surface mining.
- For oil and natural gas production and transport in this study, the total production for the 2005 base year is based on Energy Balance Table (IEA, 2007). The regional share of oil and gas production in the global market is also fixed at the 2005 level.
- It is important to note that no clear method exists for measuring the transport volumes of oil and natural gases. The Annex I countries reported their national GHG inventory in different ways under the UNFCCC. For example, some countries assumed that the transport and production volumes were equal, while others assumed that the transport volumes were 10 to 1000 times larger or smaller than the production volumes. This study assumes that the transport and production volumes are equal.
- This study links the energy supply and demand sides, thus energy supply and demand are consistent across sectors and regions. The given final energy demand is used to estimate the primary energy consumption for the power generation sector, and fugitive emissions from fuels such as coal, oil, and gas production are estimated using the given primary energy demand.

3) Results in 23 regions

- Figure 22 shows an example of the assumed ratio of underground to surface coal mining. The ratio of underground to surface coal mining will change in 2020 according to resource restriction. However, no clear statistical data exists for resource restriction and the ratio of underground to surface coals. Thus, in this study, the ratio of underground to surface coal is set at the 2005 level.

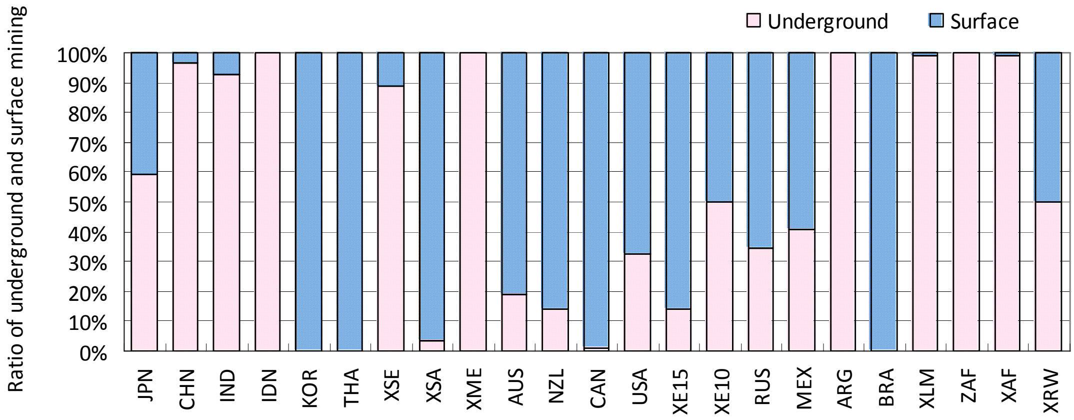


Figure 22 Assumption of ratio of underground and surface coal mining in 2005

3.4.7 Fluorocarbon emissions

3.4.7.1 HFCs

1) Overview

- Since 1930s, CFCs and HCFCs have been consumed for various purposes such as refrigerants, aerosol propellants, opened and closed foams and solvents, and HFCs have been used as alternatives for CFCs and HCFCs since 1990s. CFCs and HCFCs were regulated as Ozone Depleting Substances (ODSs) and the phase-out schedules of the production and consumption of ODSs were established under the Montreal Protocol in 1987 as shown in Figure 23. This means that, the more CFCs and HCFCs are regulated, the more HFCs will be used as refrigerants, foams, solvents and aerosol propellants in the world. This trend will continue until new alternatives for HFCs become mainstream options in the future. Thus, when future HFC emission scenarios are examined, it is also necessary to take into consideration the phase-out schedules of CFCs and HCFCs.

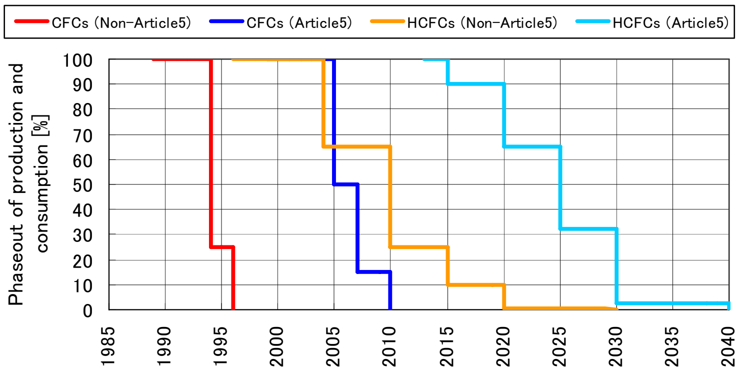


Figure 23 Phase-out schedules of the production and consumption of CFCs and HCFCs under the Montreal Protocol

・ There are several types of HFCs. The types considered are shown in Table 13.

Table 13 Target gases and services of HFCs, HCFCs and CFCs

Service	Target gases
By-product of HCFC-22	HFC-23
Refrigerants	HFC-134a, R-410A, R-507A, R-502, HFC-236fa, CFC-12, CFC-11, HCFC-22, CFC-115
Foams (closed, open)	HFC-134a, HFC-152a, CFC-11, CFC-12, HCFC-141b, HCFC-142b, HCFC-22
Aerosol propellants	HFC-134a, HFC-152a, HFC-227ea, CFC-12, CFC-11, CFC-114
Solvents	HFC-134a, HFC-43-10mee, CFC-113, CFC-11, CFC-12, HCFC-141b, HCFC-22, HCFC-225,
Others	HFC-23, HFC-134a, HFC-125, HFC-236fa, HFC-227ea

2) Methodology and assumption

・ Consumption of the target gases are estimated by region, service type, and gas type using several data sources, including UNFCCC(2008), UNEP(2005), AFEAR(2008), and Hanaoka, et al.,(2004). Thereafter, consumption of HFCs by service type and gas type in the 23 regions are estimated by considering socio-economic data and the phase-out schedules of the Montreal Protocol.

・ In order to calculate the overall releases into the atmosphere, it is necessary to take into account the time delays between consumption and emission for each category and end-use. In some categories, such as aerosol propellants, opened foams, and solvents, HFCs are directly released into the atmosphere at the time they are consumed. On the other hand, in some categories, such as refrigerants and closed foams, the HFCs are hermetically closed in appliances and released into the atmosphere when the appliances are scrapped and disposed of.

・ Thus, based on various data sources, such as AFEAR(2008), McCulloch et al., (1998), WMO/UNEP (1999), and IPCC/UNEP (2005), the emissions functions are determined by considering the time delays between consumption and emissions and depend on different service types in each end-use category.

3) Results in 23 regions

・ Figure 24 shows an example of assumption of ratio of HFCs usage in 2020. Refrigerant in refrigeration and air conditioning equipment accounts for large amount in HFC uses.

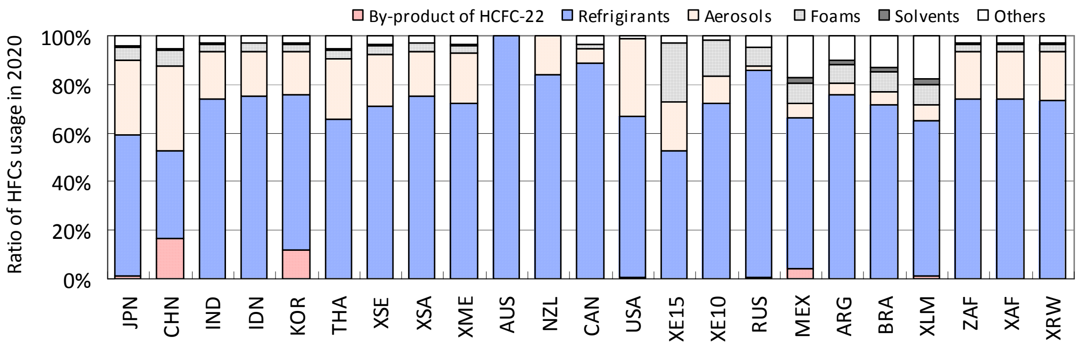


Figure 24 ratio of HFCs usage in 2020

3.4.7.2 PFCs and SF_6

1) Overview

- PFCs are used for aluminium smelting, etching in semiconductor manufacturing and liquid crystal, and other similar applications. SF_6 are used for electric utilities, magnesium smelting, and etching in semiconductor manufacturing and liquid crystal. All these service types are considered in this study.

2) Methodology and assumption

- Due to the lack of data sources for the driving forces for PFCs and SF_6, the consumption of PFCs and SF_6 is estimated by considering past trends and socio-economic data, while future consumption is estimated from several data sources, including UNFCCC(2008), Schaefer, et al., (2006), USEPA(2006), the Industrial Commodity Production Statistics Database (UN, 2005b), and IPCC SRES(2000).
- PFCs and SF_6 are directly used and released into the atmosphere at the time they are consumed. Thus, this study retains its rigor even though it does not take into account the time delays between consumption and emission.

3) Results in 23 regions

-
- Figure 25 shows an example of assumption of ratio of PFCs and SF6 usage in 2020. The major emission sources vary depending on the socio-economic characteristics of each region. For example, emissions from aluminium and magnesium smelting are major sources in some countries, meanwhile electric utilities account for large share of emissions in other countries.

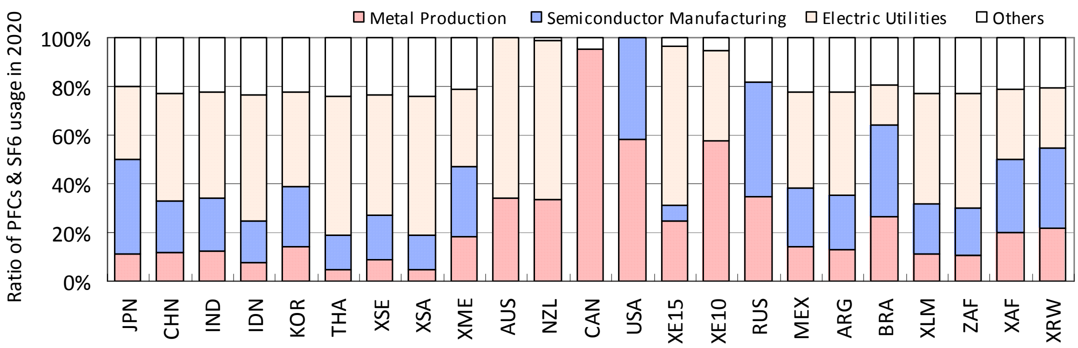


Figure 25 Ratio of PFCs and SF6 usage in 2020

3.5 Mitigation technology options

To estimate reduction potentials and mitigation costs, detailed technology options and information about them such as lifetime, diffusion rate, energy and efficiency, were assembled in the database. The technology options considered in this study are described as the list shown in Table 14. Other mitigation options are available in some sectors, but cannot be considered in this study due to a lack of data for CO_2 and N_2O mitigation technologies in the industrial process, N_2O mitigation technologies in waste water management, etc.

It is important to note that this study is based on realistic and currently existing technologies and does not take into account future innovative technologies that are expected to appear in 2020. For example, carbon capture and storage (CCS) (IPCC, 2006b) is likely to have a large effect on mitigation measures. However, the feasibility of CCS is still being studied and lacks data regarding location, volume, and cost. Therefore, this study does not take into account CCS as a mitigation measure.

It is also important to note that, under the reference case, share of nuclear power generation in the Energy Supply sector is considered under the baseline at the same level reported by IEA world Energy Outlook(IEA, 2007a), but it is not considered as a mitigation measure in this study.

Table 14 List of technology options for mitigation measures

Sector	Category	Technology options
Power generation	Coal power plant	Efficient coal power plant, PFBC (Pressurized fluidized bed combustion), IGCC (Integrated Gasification Combined Cycle)
	Gas power plant	Efficient gas power plant, ACC (Advanced Combined Cycle)
	Renewables	Wind power, Photovoltaics, Biomass power plant
Industry	Steel	Coke oven (Coke gas recovery, Automatic combustion, Coal wet adjustment , Coke dry type quenching, COG latent heat recovery, Next generation coke oven), Sinter furnace (Automatic igniter, Cooler waste heat recovery, Mainly waste heat recovery, Efficient igniter), Blast furnace(Large size blast furnace, Blast furnace gas recovery, Wet top pressure recovery turbine, Dry top pressure recovery turbine, Heat recovery of hot blast stove, Coal injection, Dry top pressure gas recovery), Basic oxygen furnace(LDG recovery, LDG latent heat recovery), Casting & rolling (Continuous caster, Hot charge rolling, Hot direct rolling, Efficient heating furnace, Heat furnace with regenerative burner, Continuous annealing lines), Electric furnace(DC electric furnace, Scrap pre-heat)
	Cement	Mill (Tube mill, Vertical mill), Kiln (Wet kiln, Semi-wet kiln, Dry long kiln, Dry shaft kiln, SP/NSP)
	Other industries	Boiler (Efficient boiler [coal, oil, gas], Boiler with combustion control [coal, oil, gas], Cogeneration [coal, oil, gas], Regenerative gas boiler), Process heat (Efficient industrial furnace [oil, gas]), Moters (Motor with Inverter control, Efficient motor)
Residential & Commercial	Cooling	Efficient cooler (sold average in developed countries in 2005, top runner, highest performance)
	Warming	Efficient air conditioner (sold average in developed countries in 2005, top runner, highest performance), Insulation (Wall insulation, Double-glazed glass with Low-e)
	Hot water	Efficient water heater [kerosene, LPG, gas, coal], CO_2 refrigerant water heater, Solar thermal water heater
	Cooking	Efficient cooking stove [kerosene, LPG, gas, coal, electricity]
	Lighting	Fluorescent of incandescent type, Fluorescent with energy saving stabilizer, Inverter type fluorescent, Hf Inverter type fluorescent
	Refrigerator	Efficient refrigerator (sold average in developed countries in 2005, top runner, highest performance)
	TV	Efficiency TV (sold average in developed countries in 2000, top runner, highest performance)
	Others	Efficient other devices
Transport	Passenger car	Efficient gasoline passenger car (Variable valve control, Cylinder deactivation, Direct injection, Engine friction reduction, Rolling resistance reduction, Aluminum body, Lightweight Chassis, Aluminum Block, CVT), Hybrid passenger gasoline car, Plug-in hybrid gasoline car, Efficient diesel passenger car (Engine friction reduction, Rolling resistance reduction, Direct injection, Common-rail, Aluminum body, Lightweight Chassis, Aluminum Block, CVT), Hybrid passenger diesel car, Plug-in hybrid diesel car, Electric passenger car, Fuel-cell passenger car,
	Truck	Efficient small-sized truck (Rolling resistance reduction, Engine improvement), Efficient large-sized truck (Rolling resistance reduction, Engine improvement)
	Passenger bus	Efficient bus (Rolling resistance reduction, Engine improvement), Hybrid bus
	Ship	Efficient ship
	Aircraft	Efficient aircraft (Engine Improvement, Weight reduction, Drag reduction)
	Rail	Efficient train
	Road transport	Bio fuel

Table14 List of technology options for mitigation measures (continued)

Sector	Category	Technology options
Agriculture	Rice cultivation	Water management (Midseason drainage, Shallow flooding, Alternative flooding and drainage), Fertilizer management (Ammonium sulfate, Addition of phosphogypsum), Cultivation management (Upland rice, Direct wet seeding, Off-season straw), Rice straw compost
	Cropland	Fertilizer management (Reduce fertilization, Nitrogen inhibitor, Spreader maintenance, Split fertilization, Sub-optimal fertilizer application), Replacing fertilizer (Replacing fertilizer with manure-N and residue), Cultivation management (Fertilizer free zone, Optimize distribution geometry, Convert fertilizational tillage to no-till), Water management (Irrigation, Drainage)
	Manure management	Anaerobic digestion (centralized plant, farm-scale plant), Covered lagoon (farm use, household use), Biogas use for cook and light from domestic storage, Manure treatment (Daily spread of manure, Slowing down anaerobic decomposition), Fixed-film digester, Plug flow digester,
	Livestock rumination	Chemical substance management (Propionate precursors, Pribiotics, Antibiotics, Antimethanogen, Mehane oxidisers), Feed management (Improve feed conversion, Improved feeding practices, High fat diet, Replace roughage with concentrates), Genetic (High genetic merit, Improved feed intake and genetics)
Waste	Municipal Solid Waste	Biological treatment, Improved oxidation through improved capping and restoration, Direct use (Direct use of landfill gas, Electricity and heat generation from landfill gas, Upgrade natural gas), Flaring landfill gas, Anaerobic digestion, Composting (windrow plant, tunnel plant, hall plant), Incineration, Paper recycling, Production of RTD (refuse-derived fuel)
Fugitive emissions	Fugitive emissions from fuel production	Coal mining (Degasification for natural gas pipeline injection, Degasification for electricity, Ventilation for electricity, Ventilation oxidizer for heat), Natural gas production and distribution (Use of instrument air, Use of low bleed pneumatic devices), Crude oil production (Flaring in place of venting, Direct use of CH_4, Reinjection of CH_4)
Fluorinated gases emission	By-product emissions	Thermal oxidation
	Refrigerants	Alternative system (Carbon dioxide, Hydrocarbons, Hydrocarbons & NH_3), Leakage reduction (for Mobile air conditioning, Commercial refrigeration, Industrial refrigeration, Stationary air conditioning DX, Stationary air conditioning chiller), Recovery (for Mobile air conditioning, Domestic refrigeration), Decomposition
	Aerosols	Alternative aerosol (Hydrocarbon aerosol propellants, Not-in-kind alternatives), 50% reduction (for Medical applications, General aerosol propellants)
	Foams	Recovery, Decomposition, Alternative system (water-blown CO_2 systems, Liquid CO_2 foam blowing, Hydrocarbon foam blowing) (for Residential Buildings, Commercial Buildings)
	Solvents	Alternative solvents (NIK aqueous, NIK semi-aqueous), Retrofit options, 50% reduction
	Semiconductor Manufacturing	Cleaning facility (NF_3 in situ clean, NF_3 remote clean), Recapture/destroy, Plasma abatement, Catalytic destruction, Thermal oxidation
	Metal Production	Retrofit（PFPB,SWPB,CWPB,VSS,HSS）in aluminium production, SO_2 replacement in magnesium production
	Electrical equipment	Leakage reduction, Device recycle
	Fire Extinguishing	Inert gas systems, Carbon dioxide systems

4 Results and discussions

4.1 Overview of case studies

Mitigation potentials, mitigation costs, and emission estimates vary depending on the settings of the socio-economic assumptions, such as population, GDP, service demands in each sector, and energy prices. In this study, these socio-economic assumptions are determined exogenously and the study does not take into account spillover effects due to introducing mitigation measures, such changes in the industrial structure and GDP, changes in the service demands in each sector, and changes in the technology and energy price.

However, mitigation potentials and costs also vary depending on both the variety of mitigation options and the settings for energy price and policy measures, such as rising carbon prices and extended payback periods. Future energy prices will fluctuate due to various factors and we find it difficult to forecast them in this study, so they are set exogenously and a sensitivity analysis of the energy price is not performed.

With regard to policy measures, several options are available for enhancing and accelerating the introduction of mitigation technologies. Two major policy instruments are 1) impose a carbon price on energy consumption, and 2) extend the payback period to introduce technologies that have high investment risk but offer high energy conservation. In this study, for the technology selection framework for various mitigation technologies, the following equation compares the incremental costs of investments and the costs of energy savings. If the operational costs of energy savings are higher than the incremental costs of capital investment, the mitigation technology is introduced instead of a conventional technology under the baseline scenario. As for the mitigation policy that extends the payback period, several options are available, such as low-interest financing or government investment in energy-saving technologies, promotion of ESCO (Energy Service Company), and visualization of the information about energy consumption and CO_2 emissions during the lifetime of the selected technology.

Incremental costs of capital investments
≦ amount of energy savings × (energy price + emission factor × carbon price)
× payback period

With regard to mitigation technologies, it is important to take into account both the demand side and the supply side. One effective measure for introducing highly efficient technologies on the demand side is extending the payback period. For the supply side, a key factor is the composition of the power sources. Section 3.3.1 describes the two distinct cases—energy security and optimization—that are used in this study. In the energy security case, social barriers restrict to a certain extent any drastic energy shift from coal and oil power plants to efficient gas power plants or renewable energies. However, in the optimization case, a drastic energy shift is allowed for reasons of cost optimization. For example, if a gas power plant is more cost effective than a existing coal or oil power plant, then the coal or oil power plant is immediately stopped and replaced with a gas power plant. Therefore, this study analyzes mitigation potentials at several marginal abatement costs (i.e., imposing carbon price) in the following three cases:

Case 1: Energy security case & reference payback period case
Case 2: Energy security case & policy payback period case
Case 3: Optimization case & reference payback period case

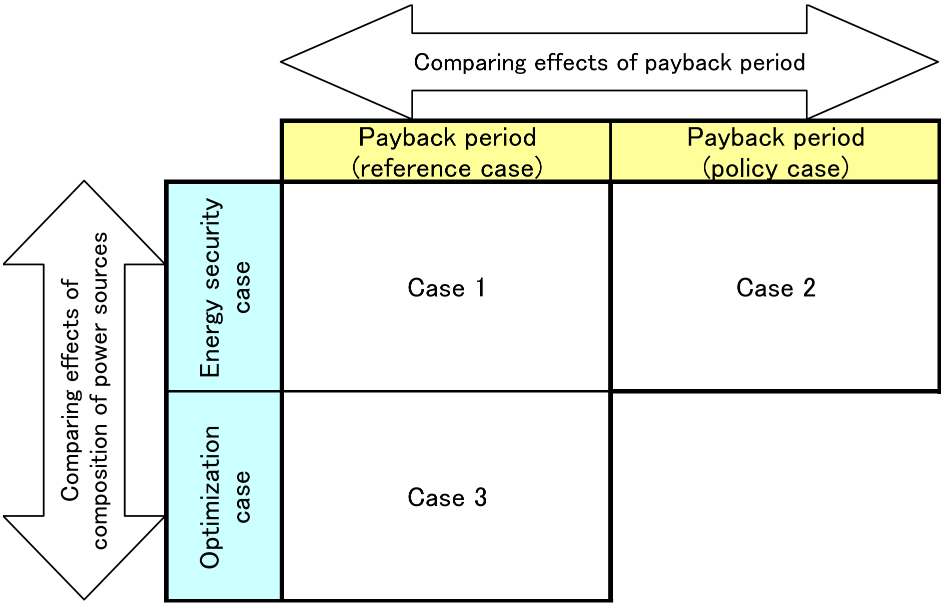


Figure 26 Overview of case studies

By comparing results in case 1 and case 2, effects of promoting high efficient technologies especially on the demand side can be analyzed, while comparison of case 1 and case 3 shows effects of a energy shift from coal and oil power plants to efficient gas power plants or renewable energy.

4.2 Coverage of mitigation options target sectors

This study focuses on the target GHGs and sectors shown in Table 1 and Table 14. However, due to inadequate data, this study could not cover all of the mitigation technologies for all anthropogenic GHGs emissions from all sectors in each region. The previous study by Hanaoka, et al. (2008) covered about 70–80% of all anthropogenic sectors. This study enlarges the coverage of the target sectors and gases, covering about 80 – 95% of the target sectors by reviewing the GHGs emissions from data sources reported by IEA (IEA, 2007e). It is important to note that the major emitting sectors are region dependent, so the sector coverage rate is lower in some countries.

4.3 Global marginal abatement cost curves and reduction potentials

Reduction potentials in 2020 were estimated by considering the market selections of realistic advanced technologies in the technology database. In the previous study by Hanaoka, et al (2008), marginal abatement cost curves were described under two different cases of discount rate for investments, enabling a comparison of the effects of mitigation measures. It was found that the features of marginal abatement cost curves differed depending on the level of discount rate for investments. In this study, three different cases were taken into account as described in Figure 26. Figure 27 shows global marginal abatement cost curves in developed and developing/EIT (economies in transition) regions in 2020. Comparing the result between developed and developing/EIT regions, there are much larger reduction potentials for cost-effective measures in developing/EIT regions. Thus, international cooperation in technology transfers and financial assistance to developing countries such as the Clean Development Mechanism under the Kyoto Protocol may play an important role in achieving GHG emission reductions. Comparing the results between case 1 and case 3, features of marginal abatement cost curves are similar when carbon price is low enough. However, more mitigation potentials are estimated at a higher carbon price above 50 US$/t-$CO_2$ eq due to the effects of a drastic energy shift from existing coal and oil power plants to new efficient gas power plants. On the other hand, comparing the results between case 1 and case 2, more mitigation potentials are estimated in case 2 due to the effects of promoting high efficient technologies especially on the demand side. There were various studies on GHG mitigation potentials and these costs in each sector in the IPCC AR4, however, mitigation potentials and marginal abatement costs will vary depending on different data settings and assumptions as described in this study. Thus it is very important to point that, when discussing regional GHG mitigation targets and comparing results between different studies, it is necessary to focus on not only methodology of its model but also socio-economic data settings and assumptions of its analysis.

The ratio of sector-wise reduction potentials in developed and developing/EIT regions under 100 US$/t$CO_2$ marginal abatement cost are shown in Figure 28. As is also described in Figure 27, reduction potentials are larger in developing/EIT regions which account for 60 - 70 % of total global potentials. In terms of sectors, large reduction potentials were identified in the power generation and industry sectors due to the use of low energy-efficient technologies in developing/EIT regions. These sectors account for 45 – 55 % of total global reduction potential.

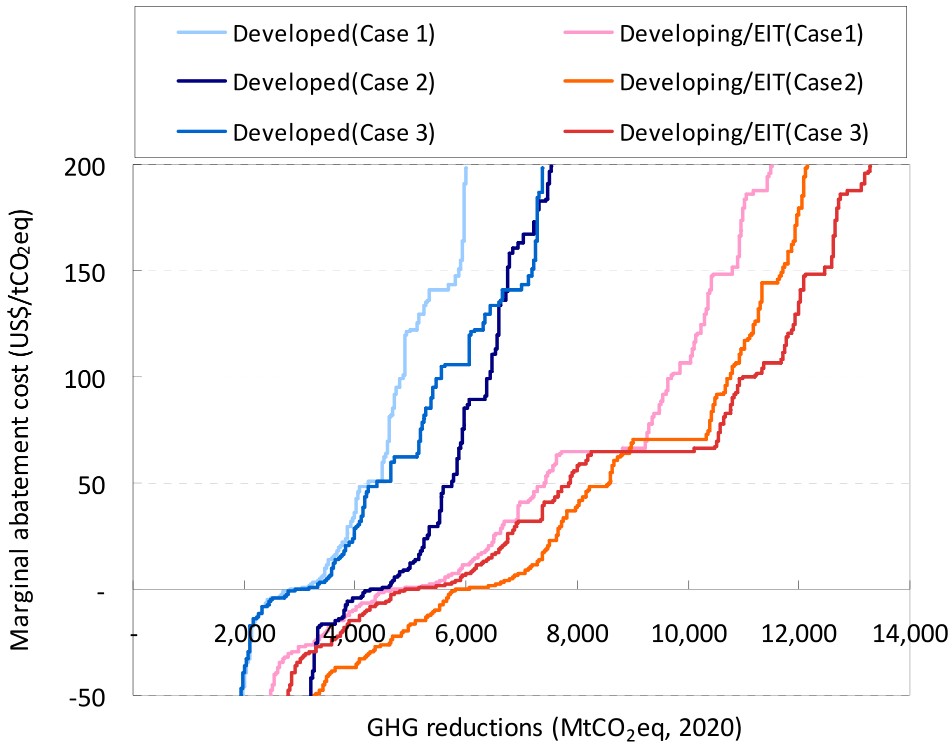
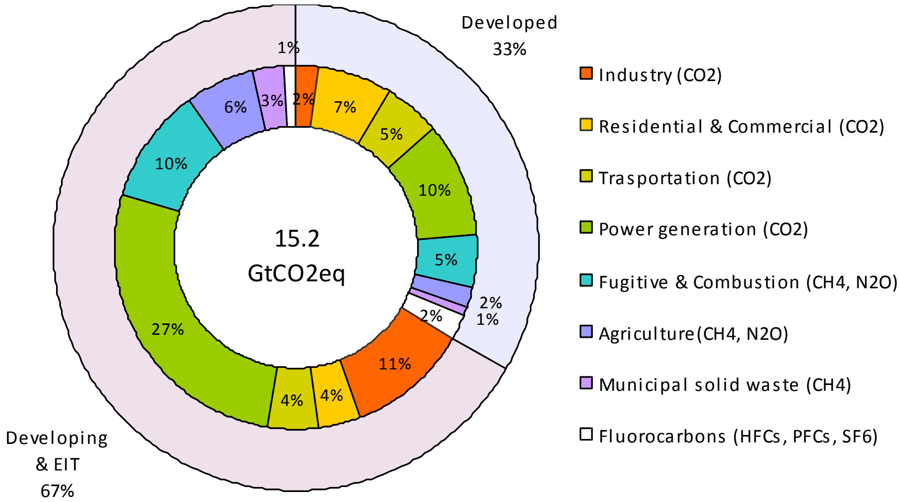
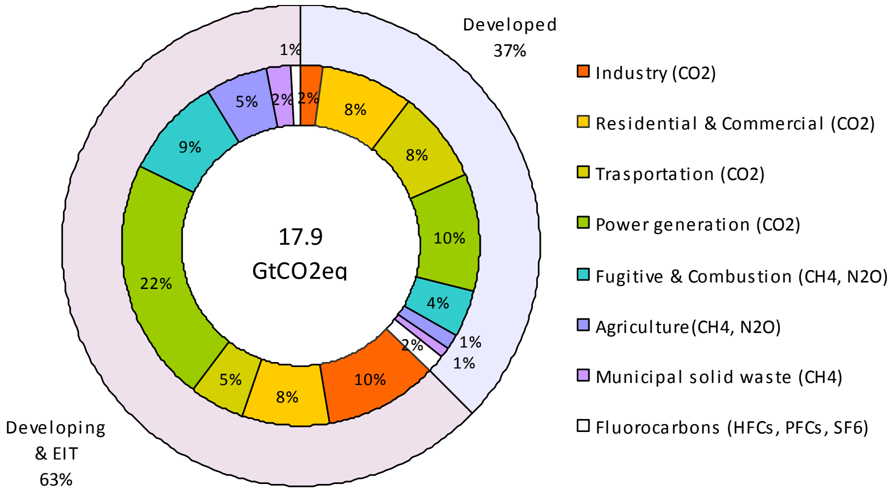


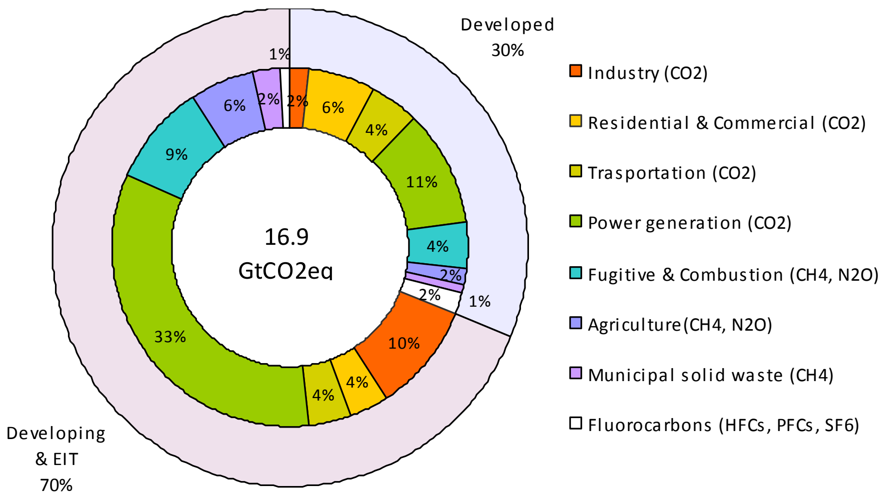
Figure 27 Marginal abatement cost curves in 2020 in Developed and Developing/EIT regions



(a) Case 1: Energy security case & reference payback period case



(b) Case 2: Energy security case & policy payback period case



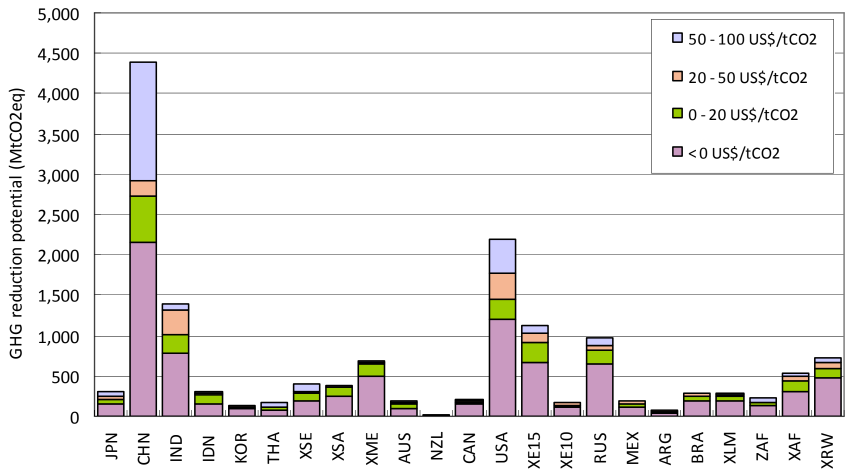
(c) Case 3: Optimization case & reference payback period case

Figure 28 Ratio of sector-wise reduction potentials from baseline in developed and developing/EIT regions under 100 US$/tCO2

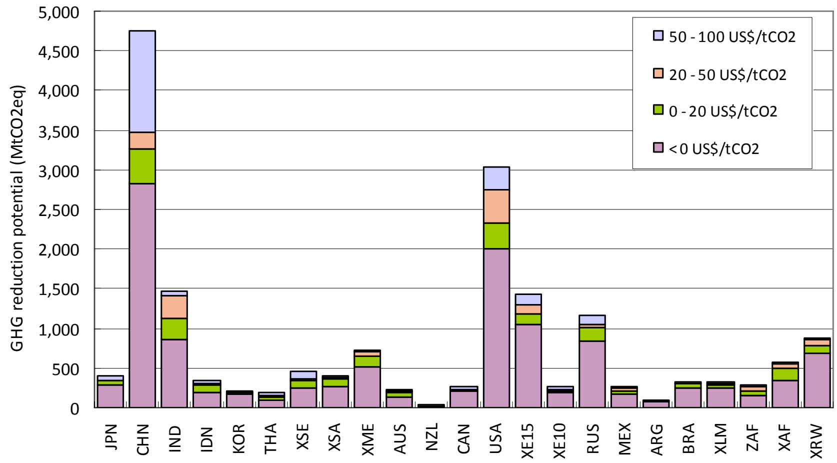
4.4 Regional reduction potentials

Figure 29 shows region-wise reduction potentials in 2020 for different cost categories under 100 US$/t$CO_2$ marginal abatement cost. The results show that China, the United States, India, EU25 and Russia are five major regions with large reduction potentials, accounting for 66 - 68% of the total reduction potential in the world. Therefore, promoting technology transfers from developed to developing countries such as China and India will be an effective measure for reducing GHG emissions under the future climate regime after the Kyoto Protocol. It was found that, under the no-regret case (i.e. 0US$/t$CO_2$ eq.), there would be large reduction potentials not only in developing/EIT but also in developed regions. However, it is important to think carefully about the meaning of the no-regret case. One of the implications is that markets and institutions do not behave perfectly because of market failures such as lack of information, lack of competition, and/or institutional failures such as inadequate regulation, so that efficient technologies have yet to be adequately introduced in the markets in these regions. Another important point to note is that, even if it is no-regret, such mitigation options cannot be introduced without imposing initial costs. Thus it is important to introduce climate policies more proactively and it is hoped that market-driven technologies are selected more efficiently in such regions.

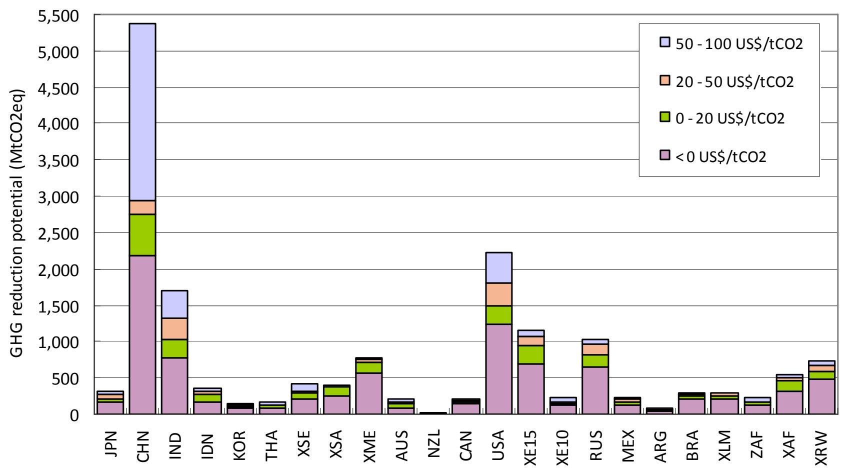
Figure 30 shows sector-wise reduction potentials for each region under 100 US$/t$CO_2$ marginal abatement cost. The major sectors which have large reduction potentials vary depending on the socio-economic characteristics of each region. For example, in the regions with high economic growth such as China and India, reduction measures in industry and power generation sectors are significant. In developing countries, it is also effective to reduce emissions from agriculture and waste sectors. In developed countries such as the US, EU and Russia, it is important to undertake mitigation policies in the industry and power generation sectors, but reduction potentials in transportation, residential and commercial sectors are also large. As for fossil fuel producing countries such as China, Russia, Middle East, the USA and India, it is effective to take measures to mitigate these fugitive emissions. There are more reduction potentials which cost more than 100 US$/t$CO_2$, especially in transport, agriculture, residential, commercial, and power generation sectors, both in developed and developing countries.



(a) Case 1: Energy security case & reference payback period case

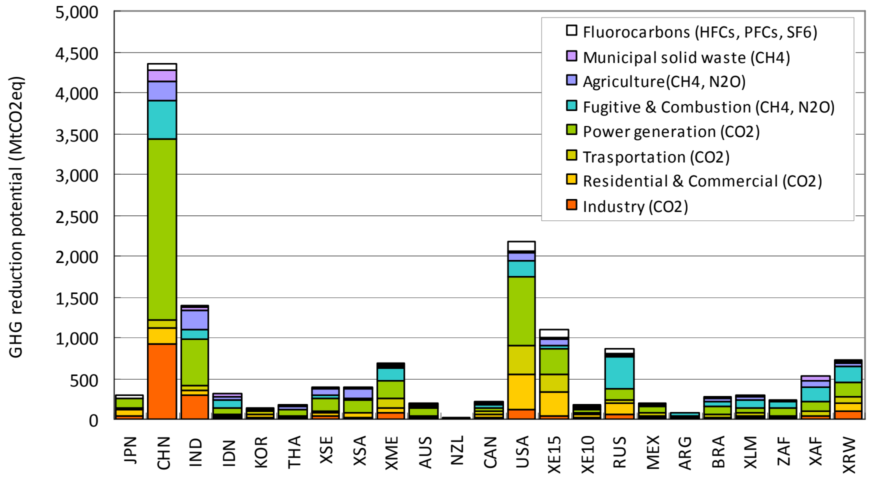


(b) Case 2: Energy security case & policy payback period case

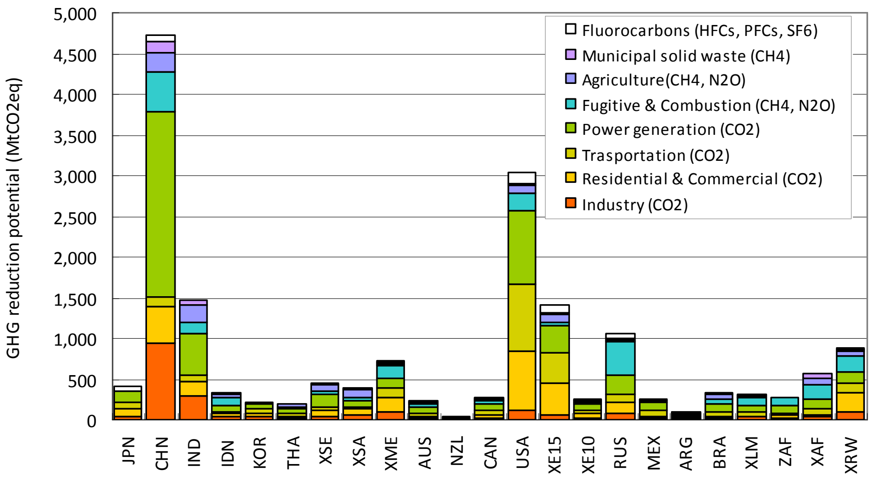


(c) Case 3: Optimization case & reference payback period case

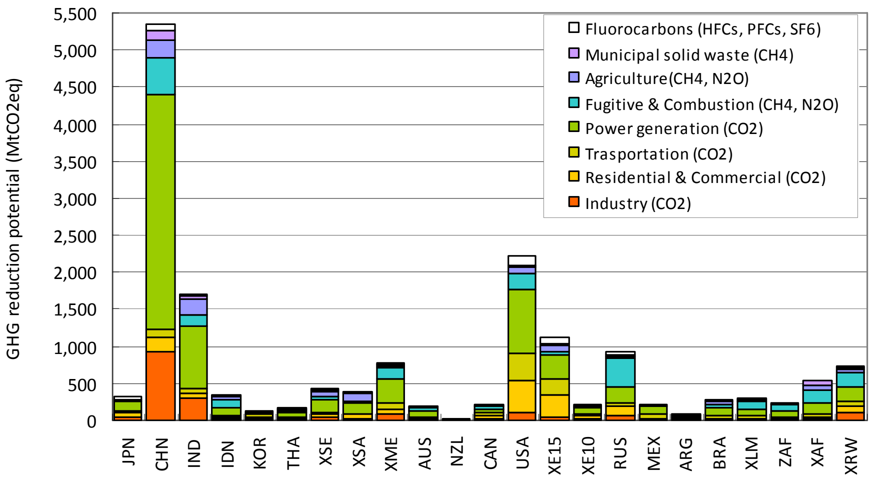
Figure 29 Region-wise reduction potentials from baseline in 2020 under 100 US$/tCO$_2$



(a) Case 1: Energy security case & reference payback period case



(b) Case 2: Energy security case & policy payback period case

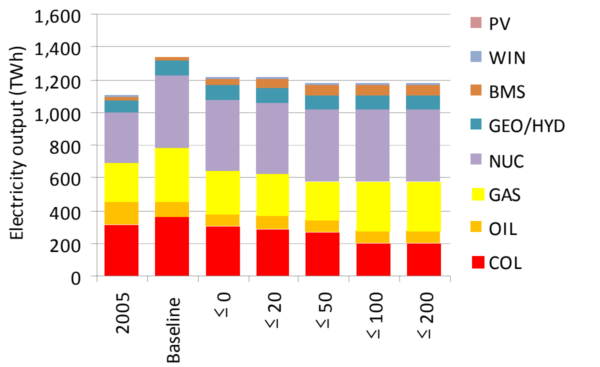


(c) Case 3: Optimization case & reference payback period case

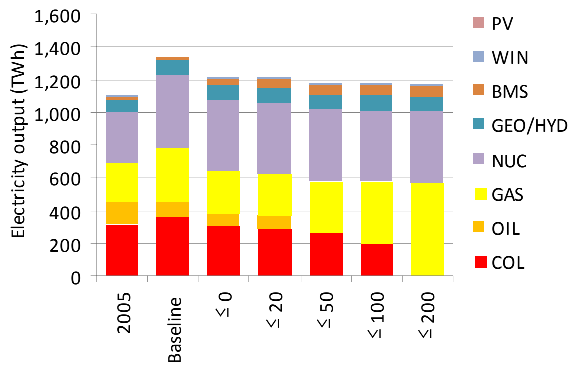
Figure 30 Sector-wise reduction potentials from baseline in 2020 under 100 US$/t$CO_2$

4.5 Composition of power sources in major developed countries

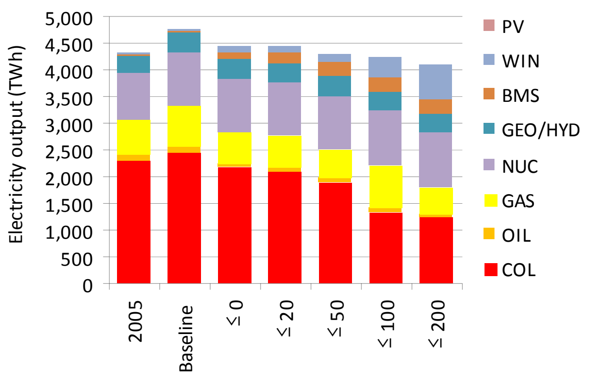
Figure 32 shows the composition of power sources in major developed countries under different marginal abatement costs. As is described in Figure 27, features of marginal abatement cost curves in case 1 and case 3 are different at a higher carbon price above 50 US$/t-$CO_2$ eq due to the effects of a drastic energy shift, which is explained by Figure 32. In case 1, by considering some social barriers such as energy security, energy costs and technological restrictions, shifts in energy from coal and oil power plants to efficient gas power plants are allowed only when existing coal and oil power plants are retired or an additional power plant is needed to meet increased energy demand. As for renewable energy such as solar, wind and biomass, the maximum limit of the ratio of renewables is set at 20% of the total energy supply in each region and country both in case 1 and case 3. However, in case 3, no restriction or barrier is considered and the composition of fossil fuel energy types is freely determined by total cost optimization. Thus, if a shift from coal and oil to gas power plants is cost effective even before existing coal and oil power plants are retired, then the existing coal and oil power plants will be immediately stopped and totally replaced by new gas power plants at around 100 to 200 US$/t$CO_2$ abatement costs. It is obvious that achieving large GHG mitigations requires various mitigation measures regarding the use of less-carbon intensive fossil fuels, the shift to non-fossil fuel energies and promotion of advanced technologies. However, as for case 3, the energy shift from coal and oil to gas is not realistic in 2020, thus it is necessary to discuss composition of power sources carefully.



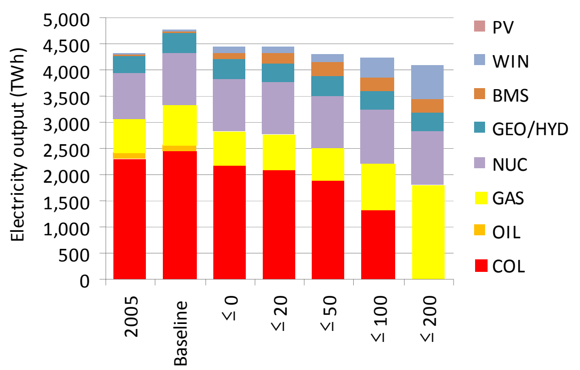
(a-1) Japan in Case 1



(b-1) Japan in Case 3

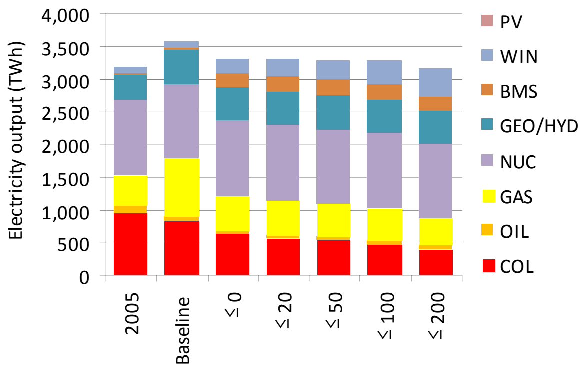


(a-2) USA in Case 1

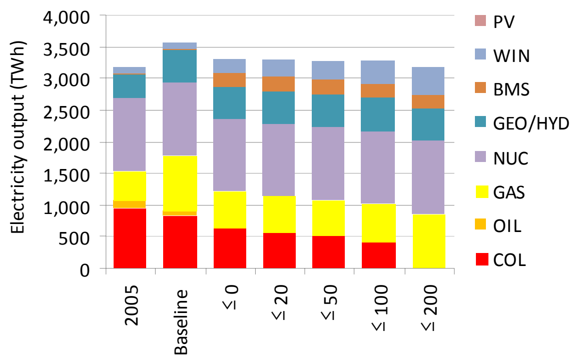


(b-2) USA in Case 3

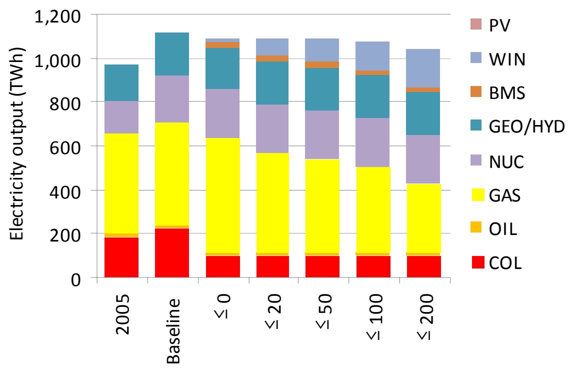
Figure 31 Composition of power sources



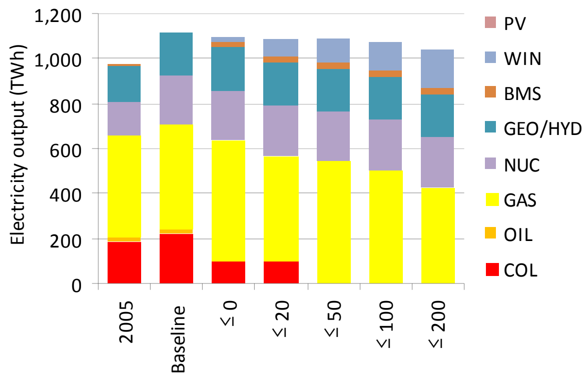
(a-3) EU25 in Case 1



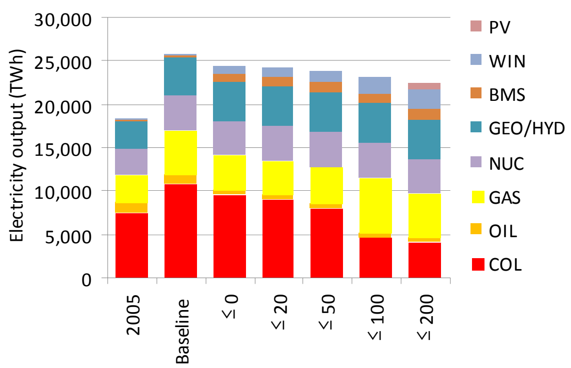
(b-3) EU25 in Case 3



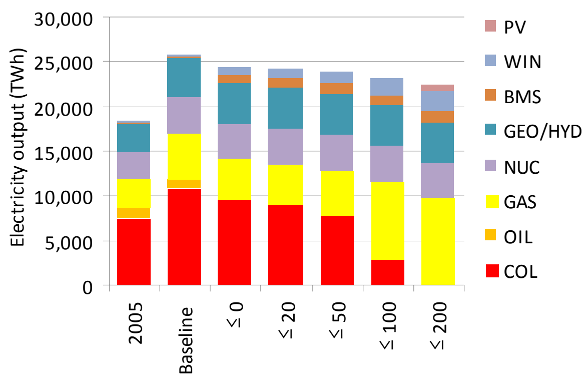
(a-4) Russia in Case 1



(b-4) Russia in Case 3



(a-5) World in Case 1



(b-5) World in Case 3

Figure 32 Composition of power sources (continued)

4.6 Emission estimates and reduction potentials

Table 15 and Figure 33 show the comparison of estimated emissions and reduction potentials in major GHG emitting countries and the world. This result shows GHG emissions from all anthropogenic GHGs from all sectors in each region.

Table 15 Emissions in major countries and regions (range of case 1 to case 3)

			1990	2005	2020			
					Frozen	< 0 US$/tCO2	< 100 US$/tCO2	< 200 US$/tCO2
Japan	CO2	GtCO2	1.11	1.26	1.35	1.07 - 1.20	1.00 - 1.11	0.97 - 1.10
	non CO2	GtCO2eq	0.14	0.15	0.18	0.18 - 0.18	0.13 - 0.13	0.12 - 0.12
	GHG	GtCO2eq	1.24	1.40	1.54	1.25 - 1.38	1.13 - 1.23	1.09 - 1.22
		vs 1990			24%	0% - 11%	-9% - -1%	-13% - -2%
		vs 2005			9%	-11% - -2%	-20% - -12%	-22% - -13%
		vs Frozen				-19% - -10%	-27% - -20%	-29% - -21%
USA	CO2	GtCO2	4.91	5.89	6.60	4.82 - 5.60	4.04 - 4.86	3.61 - 4.45
	non CO2	GtCO2eq	1.40	1.37	1.74	1.51 - 1.54	1.27 - 1.29	1.24 - 1.25
	GHG	GtCO2eq	6.30	7.26	8.34	6.33 - 7.14	5.31 - 6.16	4.86 - 5.70
		vs 1990			32%	0% - 13%	-16% - -2%	-23% - -9%
		vs 2005			15%	-13% - -2%	-27% - -15%	-33% - -21%
		vs Frozen				-24% - -14%	-36% - -26%	-42% - -32%
EU25	CO2	GtCO2	4.00	3.99	4.34	3.20 - 3.62	2.97 - 3.31	2.85 - 3.12
	non CO2	GtCO2eq	1.07	0.97	1.16	1.09 - 1.10	0.88 - 0.89	0.86 - 0.86
	GHG	GtCO2eq	5.08	4.96	5.50	4.29 - 4.72	3.85 - 4.19	3.71 - 3.99
		vs 1990			8%	-16% - -7%	-24% - -17%	-27% - -21%
		vs 2005			11%	-14% - -5%	-22% - -16%	-25% - -20%
		vs Frozen				-22% - -14%	-30% - -24%	-33% - -27%
China	CO2	GtCO2	2.42	5.73	10.79	8.42 - 9.02	6.35 - 7.32	5.82 - 6.79
	non CO2	GtCO2eq	1.37	1.68	2.21	1.80 - 1.82	1.27 - 1.29	1.18 - 1.22
	GHG	GtCO2eq	3.79	7.41	13.00	10.21 - 10.84	7.62 - 8.61	7.00 - 8.01
		vs 1990			243%	169% - 186%	101% - 127%	85% - 111%
		vs 2005			75%	38% - 46%	3% - 16%	-6% - 8%
		vs Frozen				-21% - -17%	-41% - -34%	-46% - -38%
India	CO2	GtCO2	0.62	1.22	2.58	1.84 - 1.92	1.30 - 1.60	1.22 - 1.53
	non CO2	GtCO2eq	0.86	1.02	1.21	1.09 - 1.09	0.79 - 0.80	0.78 - 0.79
	GHG	GtCO2eq	1.48	2.24	3.79	2.92 - 3.01	2.09 - 2.40	2.00 - 2.32
		vs 1990			156%	98% - 104%	42% - 62%	36% - 57%
		vs 2005			69%	30% - 34%	-7% - 7%	-11% - 3%
		vs Frozen				-23% - -20%	-45% - -37%	-47% - -39%
Russia	CO2	GtCO2	2.26	1.60	2.00	1.57 - 1.66	1.44 - 1.53	1.31 - 1.50
	non CO2	GtCO2eq	0.79	0.60	0.85	0.52 - 0.54	0.34 - 0.37	0.33 - 0.37
	GHG	GtCO2eq	3.06	2.20	2.85	2.08 - 2.20	1.79 - 1.89	1.65 - 1.85
		vs 1990			-7%	-32% - -28%	-42% - -38%	-46% - -40%
		vs 2005			30%	-5% - 0%	-19% - -14%	-25% - -16%
		vs Frozen				-27% - -23%	-37% - -34%	-42% - -35%
Developed	CO2	GtCO2	14.31	17.07	16.07	12.01 - 13.58	10.68 - 12.15	9.97 - 11.43
	non CO2	GtCO2eq	4.28	5.33	4.88	4.06 - 4.13	3.25 - 3.32	3.16 - 3.22
	GHG	GtCO2eq	18.59	22.39	20.95	16.07 - 17.71	13.92 - 15.46	13.19 - 14.64
		vs 1990			13%	-14% - -5%	-25% - -17%	-29% - -21%
		vs 2005			-6%	-28% - -21%	-38% - -31%	-41% - -35%
		vs Frozen				-23% - -15%	-34% - -26%	-37% - -30%
Developing & EIT	CO2	GtCO2	8.07	21.08	25.33	19.28 - 20.69	16.40 - 17.90	14.95 - 16.80
	non CO2	GtCO2eq	6.70	9.83	10.04	8.62 - 8.73	6.75 - 6.82	6.52 - 6.57
	GHG	GtCO2eq	14.77	30.91	35.38	27.90 - 29.42	23.20 - 24.72	21.48 - 23.37
		vs 1990			140%	89% - 99%	57% - 67%	45% - 58%
		vs 2005			14%	-10% - -5%	-25% - -20%	-31% - -24%
		vs Frozen				-21% - -17%	-34% - -30%	-39% - -34%
World	CO2	GtCO2	21.30	28.65	40.63	30.83 - 33.63	27.17 - 29.55	24.66 - 27.82
	non CO2	GtCO2eq	10.16	11.33	14.17	12.11 - 12.28	9.53 - 9.66	9.23 - 9.31
	GHG	GtCO2eq	31.46	39.98	54.80	42.94 - 45.90	36.70 - 39.20	33.95 - 37.13
		vs 1990			74%	36% - 46%	17% - 25%	8% - 18%
		vs 2005			37%	7% - 15%	-8% - -2%	-15% - -7%
		vs Frozen				-22% - -16%	-33% - -28%	-38% - -32%

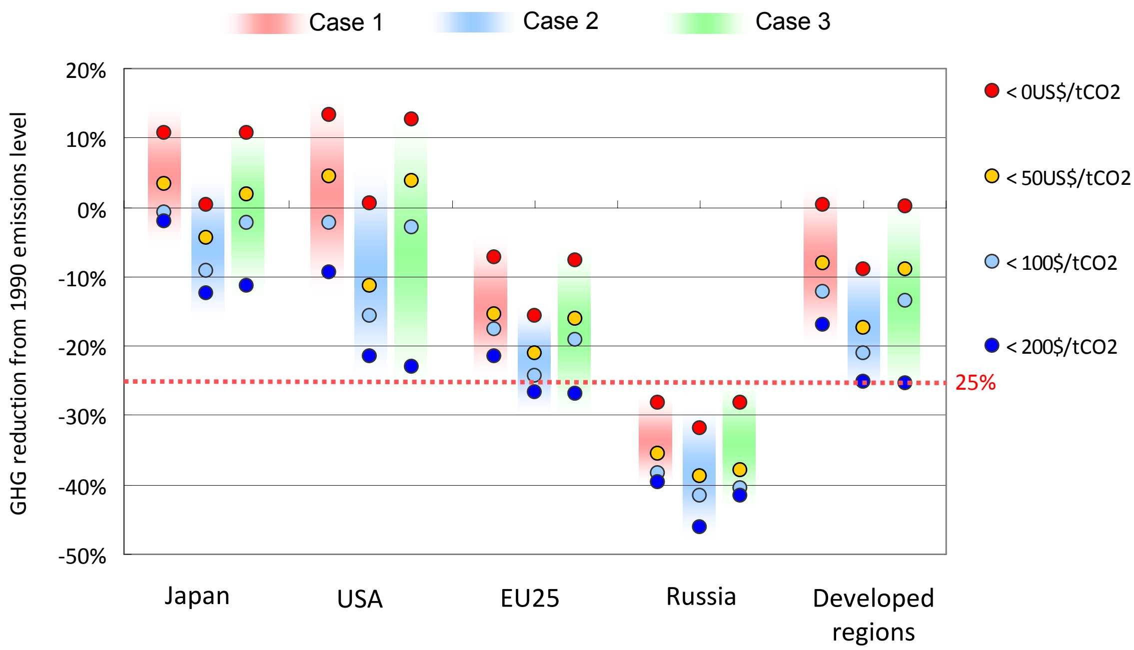


Figure 33 Comparison among developed countries at the same level of marginal abatement costs

It was found that, by introducing mitigation technologies under 100 US$/t$CO_2$ marginal abatement cost, a large amount of reduction potential can be achieved as compared to the baseline (i.e. technology frozen case) in 2020. However, the emissions in 2020 still exceed the level of emissions in 1990 in the world due to the effects of increase of the future service demands. The same feature can be seen in developing/EIT regions including China and India. Moreover, in China and India, mitigation measures under 200 US$/t$CO_2$ marginal abatement cost are not yet enough to reduce emissions lower than the level in 1990. For example, In China, high increase of the future service demands in power generation, industry, and transport sectors is expected. It implies that, in China, mitigation measures based on realistic and currently existing technologies are not enough to reduce GHG emissions, and changes in the industrial structure and service demands are also required to achieve the Low Carbon Society.

In Japan and the USA, by introducing mitigation technologies under 100 US$/t$CO_2$ marginal abatement cost, a certain amount of reduction potential can be achieved to reduce emissions lower than the level in 1990, around -9 to -1 % and -16 to -2 % in Japan and the USA respectively, In Russia and EU25 (including Western EU and Eastern EU), there are more available capacity to reduce emissions compared to Japan and USA. In order to achieve a 25% reduction target from the level in 1990 in developed countries under the equal abatement cost (i.e. 200 US$/t$CO_2$ abatement cost in this study), Japan, USA, EU25 and Russia are required to reduce GHG emissions around -11 ~ - 13%, -21 ~ -23 %, -27 %, -42 ~ -46 % respectively from the level in 1990.

It is important to note that the baseline GHG emissions in 2020 are estimated under the technology-frozen case (i.e. when future share and energy efficiency of technologies are fixed at the same level as in the base year) which does not take into account changes in the industrial structure. Moreover, future service demands are exogenous parameters in this study, so that changes in the industrial structure and service demands due to introducing mitigation measures such as compact city, modal shift, and public-awareness actions are not taken into account. Thus baseline emissions and reduction potentials may be overestimated as compared to the technology-frozen case.

Another important point to note is that this study is based on realistic and currently existing technologies, and future innovative technologies expected in 2020 are not taken into account. Therefore, by including future innovation technologies in this analysis, it is expected that the emission would be reduced more than the amount shown in Table 15 and Figure 33. Moreover, due to the lack of data availability of technologies, some mitigation options in some target sectors were not considered in this study. Therefore, by enlarging the coverage of mitigation options by collecting more comprehensive international data, the emissions are expected to be reduced further.

Therefore, while the assumptions of technology-frozen case and non-accounting of possible changes in industrial structure and service demands have led to an overestimation of the baseline and reduction potential, on the other hand, the non-consideration of future innovations and wider set of mitigation options has contributed to an underestimation of reduction potential. Though the direction of net effect of these two opposing deviations is not certain, it is crucial to be aware of these caveats. However, in order to promote drastic GHG reductions, it is important to think of not only efficiency improvement of current technologies but also the future innovations and changes of social structure towards the Low Carbon Society.

It is also necessary to note that this study estimated reduction potentials compared to the technology-frozen case under the definition of reduction potentials described in Section 2.4. Hence reduction potentials under the no regret case would be large as shown in Figure 29. However, such mitigation options under the no regret case cannot be introduced without imposing initial costs. As there would be certain mitigation technologies existing in developed countries but not in developing countries, international cooperation towards technology transfers and financial assistance to developing countries may play an important role.

4.7 Sector-wise comparison of this study with the IPCC AR4

The IPCC Fourth Assessment Report Working Group III[3)] (AR4 WG3) provides an in-depth analysis of mitigation options, GHG reduction potentials and costs by reviewing various literature, and reports the mitigation measures by sector in seven chapters on energy supply, transport, buildings, industry, agriculture, forestry, and waste management. In addition, the IPCC AR4 WG3 provides one additional chapter (Chapter 11) dealing with the cross-sectoral issues that combine information from bottom-up technological studies with results of top-down modeling exercises in the various sectors. Figure 34 shows the comparison of this study in case 2 with the results shown in Table 11.3, page 632, Chapter 11 of the IPCC AR4 WG3 (which summarizes economic potentials for GHG mitigation for different cost categories in each sector under 100 US$/t$CO_2$ eq marginal abatement cost). However, it must be noted that the temporal horizon is different between this study and the results in Table 11.3 in the IPCC AR4 WG3 which shows mitigation potentials in 2030.

The results of reduction potentials in this study are on the whole lower than those in the IPCC AR4 WG3, partly because assumptions of activity levels are different due to the difference in temporal horizons. Moreover, the IPCC AR4 WG3 covers a larger variety of mitigation options so that the amount of mitigation potential is much larger in the IPCC AR4 than in this study. For example, the following mitigation options are taken into account in the IPCC AR4 but not in this study: transport technologies such as fuel-cell electric vehicles, residential and commercial technologies such as building energy management systems, and industrial technologies such as in the petrochemical sectors. Moreover, the potential in the agriculture sector includes CO_2 emissions arising from agricultural activities that are taken into account in the IPCC AR4 but not in this study. Another reason for the difference is the level of the annual discount rate. Economic potentials for GHG mitigation vary widely according to annual discount rate and target sectors. Thus it is important to take into account the differences of annual discount rate and target sectors before comparing the results between different reports.

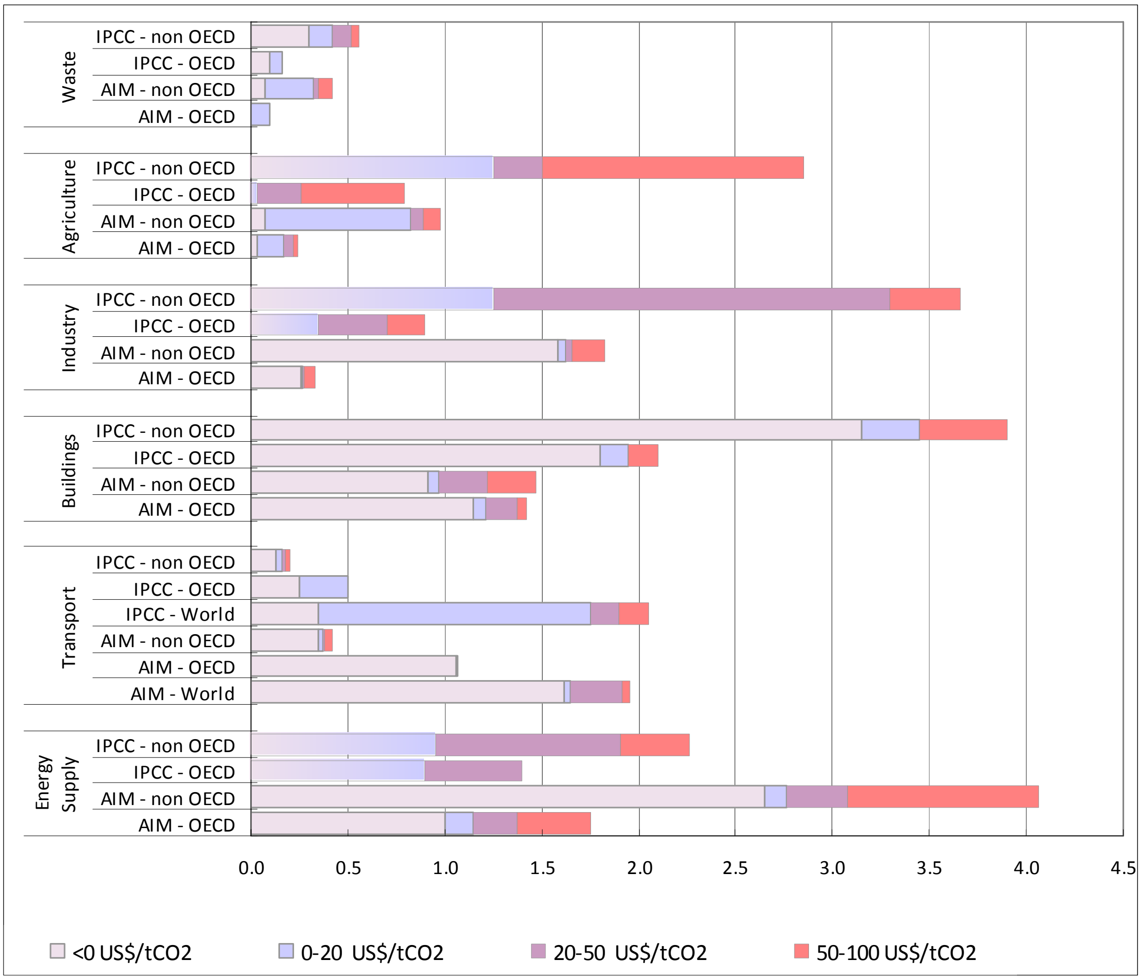


Figure 34 Comparison of this study in case 2 with the IPCC AR4 WG3

5 Conclusion

Based on the detailed technology database, emission reduction potentials and mitigation costs in world regions in 2020 were evaluated. It can be concluded that:

1) Comparing different settings of payback period for technology selections and composition of power sources, mitigation potentials in 2020 are estimated in the range between 15.2 to 17.9 $GtCO_2$ eq in global under 100 US$/$tCO_2$ marginal abatement cost.
2) China, the United States, India, Western Europe and Russia are five major regions with large reduction potentials, accounting for 66 -68% of the total reduction potential in the world.
3) In order to achieve a 25% reduction target from the level in 1990 in developed countries under the equal abatement cost (i.e. 200 US$/$tCO_2$ marginal abatement cost in this study), Japan, USA, EU25 and Russia are required to reduce GHG emissions around -11 ~ - 13%, -21 ~ -23 %, -27 %, -42 ~ -46 % respectively from the level in 1990
4) The major sectors which have large reduction potentials vary depending on the socio-economic characteristics of each region. In general, large reduction potentials exist in power generation and industry due to the use of low energy-efficient technologies especially in developing/EIT countries, and these sectors account for approximately 45~55% of the total global reduction potential.
5) There is a much larger potential for cost-effective measures in developing countries, therefore international cooperation such as technology transfer and financial assistance to developing countries will play an important role towards achieving GHG emissions reductions.
6) Although a large amount of reduction potential is estimated in 2020, it is not enough compared to the emissions in 1990 in the world, especially in developing countries due to the rapid increase of economic growth and realistic and currently existing technologies are not enough to reduce GHG emissions. In order to promote drastic GHG reductions, it is important to think of not only efficiency improvement of current technologies but also the future innovations and changes of social structure towards the Low Carbon Society.

However, this study has certain caveats. The following points must be kept in mind while interpreting the results.

a) The implementation of no-regret mitigation options in both developed and developing countries may require initial costs to overcome various barriers.
b) This study is based on realistic and currently existing technologies, and future innovative technologies expected in 2020 are not taken into account. Moreover, the coverage of some realistic and currently existing technology options for this mitigation analysis is limited due to the lack of data availability. Therefore, this study may underestimate mitigation potentials as compared to IPCC AR4, and it may be possible to reduce more if innovative technologies become available in the future.

c) On the other hand, the assumptions of technology-frozen case and non-accounting of possible changes in industrial structure and service demands have led to an overestimation of the baseline and reduction potential. Though the direction of net effect of these two opposing deviations is not certain, it is crucial to be aware of these caveats.
d) Economic potentials for GHG mitigation in this study are different as compared to the IPCC AR4. It is important to take into account the differences of the annual discount rate, target GHGs and target sectors before comparing the results between different reports.

It is necessary to enlarge the coverage of target sectors, target GHGs and mitigation options by collecting international data, to continue to develop the database, and to evaluate GHG mitigation potentials and costs more comprehensively for various sectors

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Appendix 1 Definition of geographical coverage

Code	Details
JPN	Japan
CHN	China
IND	India
IDN	Indonesia
KOR	Korea
THA	Thailand
XSE	Brunei Darussalam, Myanmar, Cambodia, Lao People's Democratic Republic, Malaysia, Philippines, Timor-Leste, Singapore, Viet Nam
XSA	Bangladesh, Bhutan, Sri Lanka, Maldives, Nepal, Pakistan
XME	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen
AUS	Australia
NZL	New Zealand
CAN	Canada
USA	United States
XE15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom
XE10	Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia
RUS	Russia
ARG	Argentina
BRA	Brazil
MEX	Mexico
XLM	Antigua and Barbuda, Bahamas, Barbados, Bolivia, Belize, Virgin Islands(British), Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Aruba, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts And Nevis, Anguilla, Saint Lucia, Saint Vincent and The Grenadines, Suriname, Trinidad And Tobago, Turks and Caicos Islands, Virgin Islands(U.S.), Uruguay, Venezuela
ZAF	South Africa
XAF	Algeria, Angola, Botswana, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Mayotte, Congo, The Democratic Republic Of The Congo, Benin, Equatorial Guinea, Ethiopia, Eritrea, Djibouti, Gabon, Gambia, Ghana, Guinea, Côte D'Ivoire, Kenya, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Guinea-Bissau, Réunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Zimbabwe, Western Sahara, Sudan, Swaziland, Togo, Tunisia, Uganda, Egypt, United Republic of Tanzania, Burkina Faso, Zambia
XRW	Afghanistan, Åland Islands, Albania, American Samoa, Andorra, Antarctica, Azerbaijan, Armenia, Bermuda, Bosnia and Herzegovina, Bouvet Island, British Indian Ocean Territory, Solomon Islands, Bulgaria, Belarus, Christmas Island, Cocos (Keeling) Islands, Cook Islands, Croatia, Faroe Islands, Fiji, French Polynesia, French Southern Territories, Georgia, Palestinian Territory, Gibraltar, Kiribati, Greenland, Guam, Heard Island And Mcdonald Islands, Holy See (Vatican City State), Iceland, Kazakhstan, Democratic People's Republic of Korea, Kyrgyzstan, Liechtenstein, Macao, Monaco, Mongolia, Republic of Moldova, Nauru, New Caledonia, Vanuatu, Niue, Norfolk Island, Norway, Northern Mariana Islands, United States Minor Outlying Islands, Federated States of Micronesia, Marshall Islands, Palau, Papua New Guinea, Pitcairn, Romania, Saint Pierre And Miquelon, San Marino, Serbia and Montenegro, Svalbard And Jan Mayen, Switzerland, Tajikistan, Tokelau, Tonga, Turkey, Turkmenistan, Tuvalu, Ukraine, The Former Yugoslav Republic of Macedonia, Uzbekistan, Wallis And Futuna, Samoa

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