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GLOBAL EMISSIONS AND MITIGATION OF GREENHOUSE GASES IN 2020

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The purpose of this study is to estimate mitigation of greenhouse gases (GHGs) in various sectors in the world regions and to evaluate marginal abatement costs (MAC) through 2020. The study estimates MAC based on a bottom-up approach with a mitigation options database. It sets a technology-frozen case as the baseline and estimates reduction potentials as 9.0-11.5 $GtCO_2eq$ on a global scale under 100 US$/$tCO_2$ marginal abatement cost in 2020. China, the United States, India, Western Europe and Russia are five major regions which account for approximately 60% of total global reduction potentials. In terms of sectors, power generation and industry account for approximately 50% of the total potentials, however, the major sectors with large reduction potentials vary depending on the socio-economic characteristics of each region. Mitigation measures of realistic and currently existing technologies under 100 US$/$tCO_2$ marginal abatement cost is not enough and the emissions in 2020 still exceed the level of emissions in 2000 due to the effects of increase of the future service demands. 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.

***Key Words** : Greenhouse gases emissions, Reduction potentials, Mitigation costs, Mitigation options, Multi-sectors and -regions*

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) suggested in the Fourth Assessment Report (AR4)[1)] 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 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 emission, 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 emission reduction potentials and these costs, and to look into the importance of international cooperation such as technology transfer mechanisms and financial assistances to developing countries.

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 through 2020. In addition, mitigation potentials and their cost-effectiveness are assessed in terms of their regional, sectoral, and technological aspects.

2. METHODOLOGY

(1) 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 21 geographical world regions as shown in Table 1. As for the gases and sectors, the 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. 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 Geographical coverage

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

(2) 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 producs (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[2)], 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[2)], 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.

(3) 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. $\Delta\hat{Q}_{l,i}^{t,\mathrm{GHG}}$, where $\Delta\hat{C}_{l,i}^{t}$, 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 ˆ : quantity per unit[1].

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

$$\Delta\hat{Q}_{l,i}^{t,GHG} = \sum_m GWP_m \cdot \left(\frac{Q_{j,i}^{0,m}}{D_{j,i}^0} - \frac{\hat{e}_{l,i}^{t,m}}{\hat{A}_{l,j,i}^t \left(1+\psi_{j,i}^t\right)} \right) \quad (1)$$

$$\Delta\hat{C}_{l,i}^t = \frac{C_{l,i}^0}{D_{j,i}^0} - \frac{\hat{C}_{l,j}^t \cdot (1+\Lambda_{l,i}^t)}{\hat{A}_{l,j,i}^t \cdot (1+\psi_{j,i}^t)} \quad (2)$$

$$\Delta S_{l,i}^{\max,t} = \frac{\Delta D_{l,j,i}^t \cdot \theta_{l,j,i}^t \cdot (1+\Lambda_{l,i}^t)}{\hat{A}_{l,j,i}^t \cdot (1+\psi_{j,i}^t)} \quad (3)$$

$$\Delta D_{l,j,i}^t = D_{j,i}^t - \sum_{l' \in (AC_{l',i}^t < AC_{l,i}^t)} \frac{S_{l',i}^{\max,t} \cdot \hat{A}_{l',j,i}^t \cdot (1+\psi_{j,i}^t)}{(1+\Lambda_{l',i}^t)} \quad (4)$$

$$\Delta Q_{pot,l,i}^{t,GHG} = \Delta\hat{Q}_{l,i}^{t,GHG} \cdot \Delta D_{l,j,i}^t \quad (5)$$

where

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

$\hat{C}_{l,i}^t$: Annual cost of supplying service j per unit operation of energy device l in region/sector i including the fixed, energy, and maintenance costs, in time period t

$C_{j,i}^0$: Annual cost of supplying service j, including the fixed, energy, and maintenance costs, in the base year t_0

$AC_{l,i}^t$: Abatement cost per unit reduction of energy device l in region/sector i in time period t

$\Delta D_{l,j,i}^t$: Maximum supply of service j by recruited energy device l in region/sector i

$D_{j,i}^0$: Service demand for service j in region/sector i in the base year t_0.

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

$Q_{j,i}^{0,m}$: Emission of gas m per unit supply of service j in region/sector i in base year t_0

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

$\psi_{j,i}^t$: Supply efficiency of service j in region/sector i in time period t.

$\theta_{l,j,i}^t$: Maximum share of energy device l for service j in region/sector i

GWP_m : Global warming potential of gas m emission per unit.

(4) Global Warming Potential values

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"[35]. These GWP values, which are defined by the IPCC, represent the direct global warming potentials relative to CO_2. It should be noted that the GWP values are defined differently in *Climate Change 1995*[34], *Climate Change 2001*[35], and *Climate Change 2007* [1]. The GWP values reported in the *Climate Change 2007* [1] 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*[34] whose values are also used for GHGs national inventory reports because of the stipulation in the Kyoto Protocol, are considered in this study.

3. DATA SETTINGS ASSUMPTION

(1) Settings of future service demands

To evaluate mitigation potentials at regional and global levels, firstly it is necessary to estimate future service demands in each service and sector. In this study, the base year and the target year are set as 2000 and 2020 respectively, and service demands in each service and sector are estimated based on various kinds of international and national statistics and outlooks as shown in Table 2. As for the socio-economic drivers, future population and GDP growth are set based on the UN World Population Prospects[4] and IPCC SRES B2 scenario[5] respectively. Global energy prices are set based on the IEA World Energy Outlook[7]. In this study, it is necessary to determine service demands exogenously and emission reduction potentials are evaluated sector-wise and region-wise. Hence this study does not take into account spillover effects due to introducing mitigation measures, such changes in the industrial structure, change of service demands, and changes in technology price and energy price, and besides, this study does not analyze the role of the international trade of the future service demands. Thus, these issues are kept beyond the scope, because the future service demands are set exogenously in this study. Table 3 shows example of service demands in major countries.

(2) Settings of payback period

In the technology options database, mitigation costs are measured by capital cost and operational the annual discount rate, the latter has a significant impact on simulation results. In this study, the annual discount rate is determined exogenously so as to fit the rate of payback period exogenously. The payback period represents the period of time required for the return on an investment such as energy savings to break 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 and which includes fixed and variable operational and maintenance cost, overhead cost, and other costs that are not included in 'fixed cost' and 'price of energy'. As the mitigation costs will vary depending on the different settings of even on the capital cost, and shorter payback periods are obviously preferable to longer payback periods especially for private

Table 2 Sources of data for future service demands

GHG	Sector	Service demands
CO_2	Power generation[note1)]	Future power generation, primary energy demand and its component ratio of energy types by region are set based on the data sources of IEA Energy Balances[6)] and IEA World Energy Outlook[7)]
	Industry	In the steel production sector, crude steel production and the component ratio of steel manufacturing processes (i.e. electric furnace, blast furnace, open hearth furnace) by region in the base year are based on IISI data[8)], and the future growth rate of steel production is set based on several data sources such as IEEJ[9)] and USDOE SAGE[10)]. In the cement production sector, cement production and the mixing rate of additives (i.e. slag and fly ash) by region in the base year are based on CEMBUREAU[40)], IEA[41)], and Worrel et al[42)], and the future growth rate of cement production is set based on WBCSD[43)]. In other industry sectors which use technologies such as boilers, process heat, motors etc, energy consumption by region, by sector, by energy type and by service type are set based on the data of IEA Energy Balances[6)] and USDOE SAGE[10)]. The future growth rate of energy consumption is based on several data sources such as the results of the AIM/CGE model[3)] and USDOE SAGE[10)].
	Transport	Energy consumption by region, by sector, by energy type and by service type is based on the data source of IEA Energy Balances[6)] and USDOE SAGE[10)], and the future growth rate of transport volume is based on several data sources such as statistical year books about vehicles, trains, ships and aircraft[11)12)13)14)], USDOE SAGE[10)] and WBCSD[15)].
	Residential & commercial	Energy consumption by region, by sector, by energy type and by service type is based on the data of IEA Energy Balances[6)] and USDOE SAGE[10)], and the future growth rate of corresponding activities, population, number of households and the diffusion rate of corresponding services are based on several data sources such as USDOE SAGE[10)], World Development Indicators[16)], World Marketing Data and Statistics[17)], and UN habitat[18)].
CH_4 N_2O	Agriculture [note2)]	Cropland area and livestock numbers by region are based on FAOSTAT data[19)], and the future growth rate of cropland area and livestock numbers are based on IFPRI[20)] and FAO data[21)]. Nitrogen fertilizer input in the base year is based on IFA/FAO/IFDC[22)23)], and fertilizer input growth on FAO data[21)]
CH_4	Waste [note2)]	The relationship between the amount of Municipal Solid Waste (MSW) and GDP per capita by region is based on the IPCC guidelines[24)], EEA[25)], and World Development Indicators[16)], and the future growth rate of MSW is based on the UN World Population Prospects under the medium fertility variant[4)]·and GDP growth on the IPCC SRES B2 scenario[5)] [note3)].
HFC, PFC, SF_6	Fluorocarbon gas emission	HFCs consumption is based on the data sources of UNEP[26)], AFEAR[27)] and several reports such as Hanaoka, et al(2004)[28)], future HFCs emissions are estimated by referring to several data sources such as IPCC/TEAP[29)], WMO/UNEP[30)], and Hanaoka, et al 2004[28)]. PFCs and SF_6 emissions are estimated by referring to several data sources such as UNFCCC[31)], the UN's Industrial Commodity Production Statistics Database [32)], Schaefer, et al[33)] and IPCC[5)].

Note 1) CO_2 emission factor by electricity consumption is reflected by the result of primary energy supply and its component ratio of energy types by region under the reference scenario by IEA[7)].
Note 2) Emission factors used for evaluation of CH_4 and N_2O emissions are based on the data of the IPCC guidelines[24)].
Note 3) For waste generation, total population in developed countries and urban population in developing countries are considered.

Table 3 Example of service demands in major countries and regions

	Year	Unit	Japan	USA	EU15	China	India	Russia	Global
Electricity generation in power generation sector	2000	TWh	1056.9	4025.7	2293.3	1355.6	555.7	876.5	14578.0
	2020	TWh	1345.8	5288.7	3034.2	6417.3	1783.9	1201.3	28638.3
	CAGR	%/year	1.2%	1.4%	1.4%	8.1%	6.0%	1.6%	3.4%
Crude steel production in industry sector	2000	Mt	106.4	101.8	163.2	127.2	26.9	59.1	836.3
	2020	Mt	106.9	124.2	163.2	492.4	86.3	106.7	1493.1
	CAGR	%/year	0.0%	1.0%	0.0%	7.0%	6.0%	3.0%	2.9%
Cement production in industry sector	2000	Mt	83.3	87.8	197.2	587.5	100.0	32.3	1655.8
	2020	Mt	66.2	109.6	213.2	2049.3	339.1	61.8	3974.7
	CAGR	%/year	-1.1%	1.1%	0.4%	6.4%	6.3%	3.3%	4.5%
Energy consumption in other industry sector	2000	Mtoe	79.2	266.9	215.9	221.8	76.5	90.2	1534.9
	2020	Mtoe	108.3	473.8	336.9	791.0	165.7	171.6	3354.7
	CAGR	%/year	1.6%	2.9%	2.2%	6.6%	3.9%	3.3%	4.0%
Energy consumption in transport sector	2000	Mtoe	87.4	578.5	282.1	82.7	41.9	40.6	1611.8
	2020	Mtoe	106.7	781.6	379.8	256.0	115.5	78.7	2661.0
	CAGR	%/year	1.0%	1.5%	1.5%	5.8%	5.2%	3.4%	2.5%
Energy consumption in residential & commercial sector	2000	Mtoe	110.2	458.3	353.0	334.0	159.1	168.7	2401.2
	2020	Mtoe	138.3	604.8	417.4	417.5	185.4	219.5	3013.0
	CAGR	%/year	1.1%	1.4%	0.8%	1.1%	0.8%	1.3%	1.1%

Note) Growth rate of each service demand is indicated by Compounded Annual Growth Rate (CAGR)

Table 4 Settings of payback period

Case	Sector	Settings of payback period
Case 1	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[36], and also the Energy Conservation Center, Japan conducted an questionnaire survey[37] 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).
	Power generation	The power generation sector is considered as a kind of public industry that takes into account low investment risks by considering governmental supports. Therefore, the payback period is considered longer and assumed as around nine to 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).
	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]).
Case 2	All sectors	Under the assumption of shorter payback periods at Case 1, only technologies with low investment risk and high energy conserving are introduced and it does not promote measures for energy conservation enough. Thus, in order to consider the lifetime of technology long enough, the payback periods are assumed longer enough. (i.e. a five % annual discount rate [note 1] was considered across all sectors and all regions).

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.

Note 2) In developing countries and economy in transition, economy is unstable and investment risk is very high, so that payback period should be considered shorter than other countries. Moreover, sense of values and stability of economy vary across countries, so that valuation standards of payback periods should be different region by region. However, in order to evaluate mitigation potentials comparatively region by region, country risks are not taken into account in this study and the same level of payback periods are assumed sector by sector across the world.

industries that take high investment risk for energy conserving technologies. Thus, from the viewpoint of sensitivity analysis of mitigation costs, two different payback periods were considered as shown in Table 4.

(3) 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 5. It is important to note that this study is based on realistic and currently existing technologies, and future innovative technologies expected in 2020 are not taken into account. For example, carbon capture and storage (CCS)[38] is one of expected future innovative technologies that is likely to have large effect on mitigation measures. However, feasibility of CCS is still being studied, and due to the lack of data availability such as location, volume and cost, CCS is not taken into account as a mitigation measure in this study. Another important point to note is that these technologies in Table 5 are the options which are used for mitigation analysis in this study. There are other mitigation options in some sectors which are not able to be considered in this study due to the lack of data availability, for example, CO_2 mitigation options in petrochemical sector, N_2O mitigation options in chemical sector, CH_4 mitigation options in fuel production and transport, and so on.

4. RESULTS AND DISCUSSIONS

(1) The coverage of target sectors

Target GHGs and sectors focused on in this study are shown in Table 2. However, due to inadequate data availability, this study could not cover all anthropogenic GHGs emissions from all sectors in each region. Figure 1 shows the coverage of target sectors in this study, by reviewing the GHGs emissions in 2000 from data source reported by IEA[39]. The bar under the thick line in each region in Figure 1 shows the percentage of the target sectors covered by this study, whereas the bar above the thick line shows the percentage of uncovered sectors. As mentioned in Figure 1, this study covers around 70 – 80 % of all anthropogenic sectors but major emitting sectors depend on regions so the coverage rate of sectors is lower in some countries than in the others. For example, in China, Middle East, Russia and Africa, the coverage rate is lower because there are large amount of CH_4 emissions from the fossil-fuel production and transportation sectors such as coal and natural gas mining in these countries as compared to other countries.

Table 5 List of technology options for mitigation measures

Sector	Category	Technology options
Power generation	Coal power plant	High-efficiency coal power plant, Pressurized fluidized bed combustion, Integrated gasification combined cycle
	Gas power plant	High-efficiency gas power plant, Advanced combined cycle
	Other renewables	Wind power, Photovoltaics, Biomass power plant
Industry	Steel	Large size coke oven, Coke gas recovery, Automatic combustion, Coke dry type quenching, Coal wet adjustment, COG latent heat recovery, Next generation coke oven, Automatic igniter, Coller waste heat recovery, Mainly waste heat recovery, High efficiency igniter, 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, LDG recovery, LDG latent heat recovery, Continuous caster, Hot charge rolling, Hot direct rolling, High efficiency heating furnace, Heat furnace with regenerative burner, Continuous annealing lines, DC electric furnace, Scrap pre-heat
	Cement	Ball mill, Tube mill, Vertical mill, Wet kiln, Semi wet/dry kiln, Dry long kiln, Vertical (Shaft) kiln, SP/NSP,
	Other industries	High-efficiency boiler (coal, oil, gas), boiler with combustion control (coal, oil, gas), cogeneration (coal, oil, gas), Regenerative gas boiler, High-efficiency industrial furnace (oil, gas), Motor with Inverter control, High efficiency motor
Residential Commercial	Cooling	High-efficiency Cooler (Sold average in developed countries in 2000, Top Runner, Highest performance)
	Warming	High-efficiency kerosene stove, LPG Stove, Gas Stove, High-efficiency air conditioner (Sold average in developed countries in 2000, Top Runner, Highest performance), Wall insulation for detached house, Wall insulation, Double-glazed Glass with Low-e
	Hot water	High-efficiency kerosene water heater, High-efficiency LPG water heater, Latent Heat Recover LPG Water Heater, Latent Heat Recover Gas Water Heater, CO2 Refrigerant water heater, Solar thermal water heater
	Cooking	High-efficiency Gas Cooking Stove(LPG, Natural gas)
	Lighting	Fluorescent of incandescent type, Fluorescent with energy saving stabilizer, Inverter type fluorescent, Hf Inverter type fluorescent
	Refrigerator	High-efficiency refrigerator(Sold average in developed countries in 2000, Top Runner, Highest performance)
	TV	High-efficiency TV (Sold average in developed countries in 2000, Top Runner, Highest performance), TV (Liquid crystal display)
Transport	Passenger car	High-efficiency passenger car, Weight reduction, Engine friction reduction, Aerodynamic drag reduction, Rolling resistance reduction, Brake drag reduction, Hybrid engine, Continuously variable transmission, VVLT & cylinder reactivation, GDI Engine
	Truck	High-efficiency truck, Engine improvement, Weight reduction, Aerodynamic drag reduction, Rolling resistance reduction, Hybrid engine
	Passenger bus	High-efficiency bus, Rolling resistance reduction for bus, Hybrid engine
	Ship	High-efficiency ship, Electric Propulsion System Using Gas Turbine
	Aircraft	High-efficiency aircraft, Engine improvement & weight reduction & drag reduction
	Rail	High-efficiency train, Regenerative braking system with VVVF
Agriculture	Rice cultivation	Water management (Midseason drainage, Shallow flooding, Alternative flooding/Drainage), fertilizer management (ammonium sulfate), upland rice, Addition of Phosphogypsum, Direct Wet Seeding, Off-season straw, Rice Straw Compost
	Cropland	Reduce fertilization, Nitrogen inhibitor, Fertilizer Free Zone, Optimize distribution geometry, fertilization management (Spreader maintenance, Split fertilization, Sub-optimal fertilizer application), Convert fertilizational tillage to no-till
	Mature management	Anaerobic Digestion (Centralized plant, Farmscale plant), Covered Digester, Covered lagoon, daily spread of manure, Complete mix digester, Plug flow digester, slowing down anaerobic decomposition
	Livestock rumination	Administration of chemical substance (Propionate precursors, Pribiotics), feed management (High Fat Diet, Improved feed intake and genetlcs, Replace roughage with concentrates)
Waste	Municipal Solid Waste	Biological Treatment, Improved oxidation through improved capping and restoration, Direct Use of Landfill Gas, Electricity and Heat Generation from landfill gas, Flaring Landfill Gas, Upgrade Natural Gas, Anaerobic Digestion, Composting (windrow plant, tunnel plant, hall plant), Incineration, Paper recycling
Fluorinated gases emission	By-product emissions	Thermal Oxidation
	Refrigerants	Alternative system (carbon dioxide, hydrocarbons, hydrocarbons & NH_3), Leakage reduction, Recovery, Decomposition
	Aerosols	Alternative aerosol (Hydrocarbon Aerosol Propellants, Not-in-kind Alternatives), 50% reduction (for Medical applications, General Aerosol Propellants)
	Foam blowing agents	Recovery, Decomposition, Alternative System (Water-blown CO_2 Systems, Liquid CO_2 Foam Blowing, Hydrocarbon Foam Blowing)
	Solvents	Alternative Solvents (NIK Aqueous, NIK Semi-Aqueous), Retrofit Options, 50% reduction
	Manufacturing	Cleaning facility (NF_3 In Situ Clean, NF_3 Remote Clean), Recapture/Destroy, Plasma Abatement, Catalytic Destruction, Thermal Oxidation, Retrofit (PFPB, SWPB, CWPB, VSS, HSS), SO_2 Replacement
	Electrical equipment	Leakage reduction, Device recycle

Note) 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.

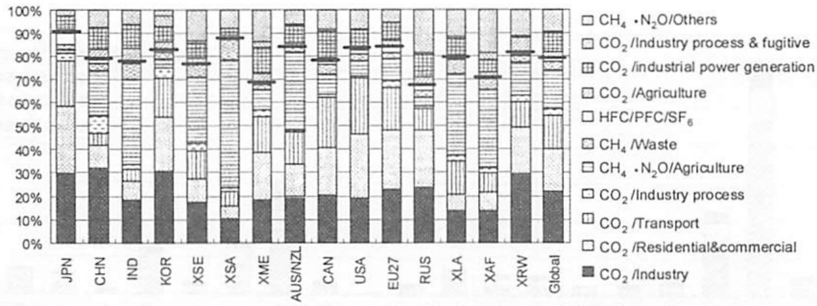


Figure 1 The coverage of target sectors in this study (Emissions in 2000 from the data source by IEA[39])

Note) This figure shows the coverage of target sectors but does not show the coverage of mitigation measures.

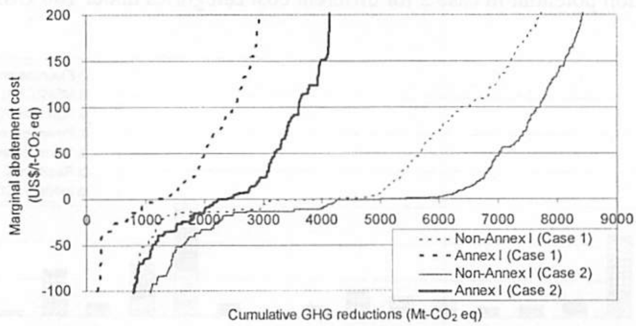


Figure 2 Marginal abatement cost curves in 2020 in Annex I and Non-Annex I regions

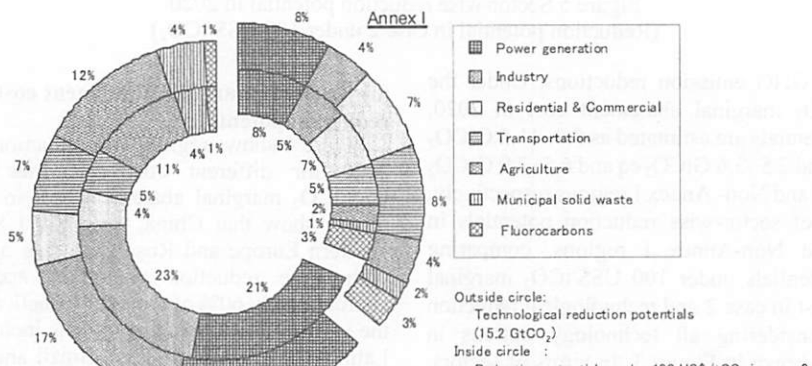


Figure 3 Ratio of sector-wise reduction potentials in Annex I and Non-Annex I regions

(2) 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. Global marginal abatement cost curves in Annex I and Non- Annex I regions in 2020 were described under two different payback period cases as shown in Figure 2, enabling a comparison of the effects of mitigation measures under different levels of marginal abatement costs. The features of marginal abatement cost curves differed depending on the level of the payback period. Under the same carbon cost in case 1 and case 2, the reduction potentials vary in the range of 1 – 1.5 $GtCO_2$ eq. Comparing the result between Annex I and Non Annex I regions, there are much larger reduction potentials for cost-effective measures in Non Annex I 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

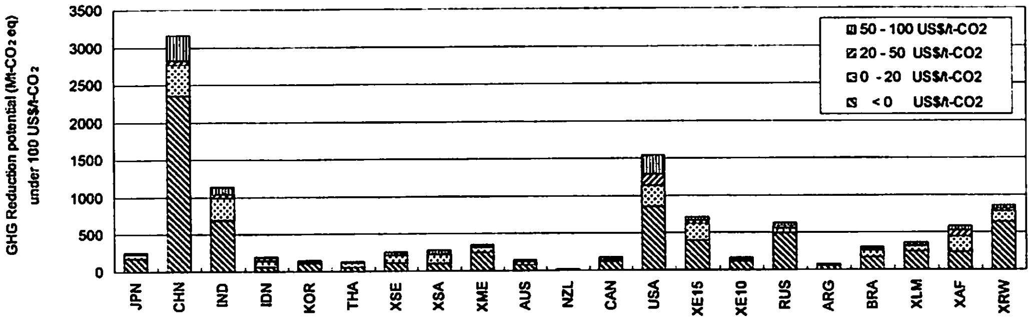


Figure 4 Region-wise reduction potential in 2020
(Reduction potential in case 2 for different cost categories under 100 US$/t$CO_2$)

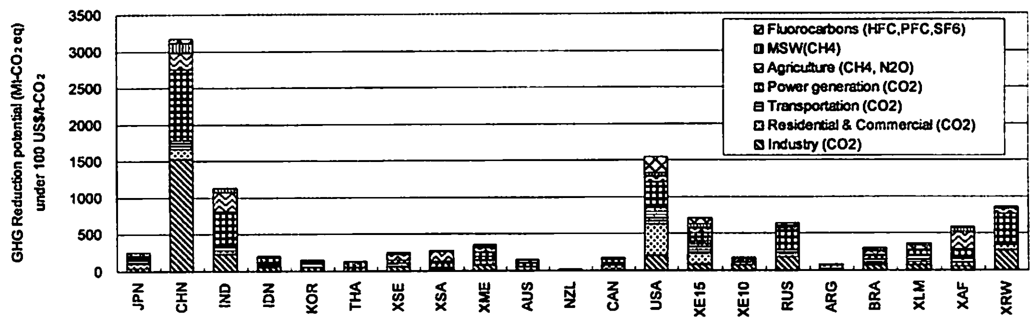


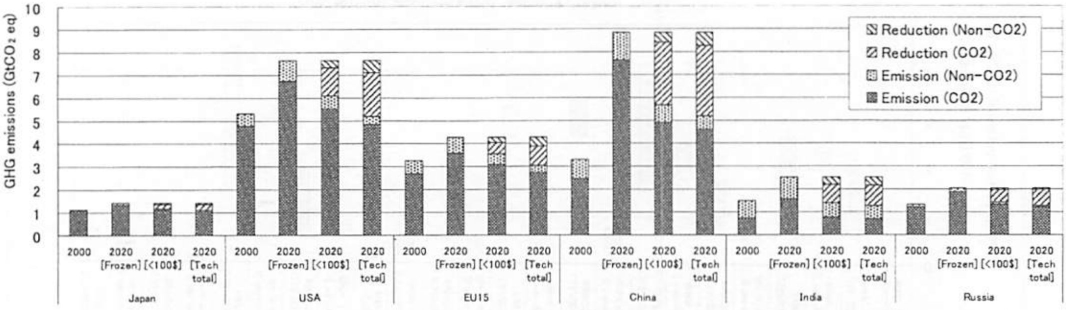
Figure 5 Sector-wise reduction potential in 2020
(Reduction potential in case 2 under 100 US$/t$CO_2$)

in achieving GHG emission reductions. Under the 100 US$/t$CO_2$ marginal abatement cost in 2020, reduction potentials are estimated as 9.0~11.5 GtCO_2 eq globally and 2.5~3.6 GtCO_2 eq and 6.5~7.9 GtCO_2 eq in Annex I and Non- Annex I regions respectively.

The ratio of sector-wise reduction potentials in Annex I and Non-Annex I regions, comparing reduction potentials under 100 US$/t$CO_2$ marginal abatement cost in case 2 and technological reduction potentials considering all technology options in Table 5, are shown in Figure 3. 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 Non-Annex I regions. These sectors account for approximately 50% of total global reduction potentials. The residential and commercial sector and transportation sector account for approximately 10 % of the total, respectively, and sectors related to non-CO_2 emissions such as agriculture, MSW and fluorocarbon emission sectors account for approximately 20 % of the total. Reduction potential is larger for agriculture and waste in Non-Annex I areas, whilst fluorocarbon emission reduction potential is greater in Annex I.

(3) Regional marginal abatement cost curves and reduction potentials

Figure 4 shows region-wise reduction potential in 2020 for different cost categories under 100 US$/t$CO_2$ marginal abatement cost in case 2. The results show that China, the United States, India, Western Europe and Russia are five major regions with large reduction potentials, accounting for approximately 60% of the total reduction potential in the world. Also, ten major regions including Africa, Latin America, Middle East, Brazil and South Asia account for approximately 80% of the total reduction potential. Therefore, promoting technology transfers from developed to developing countries such as China and India will be an effective measure for reducing GHG emission 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 Non-Annex I but also in Annex I 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



		Japan	USA	EU15	China	India	Russia
Reduction ratio in the case 2 under 100 US$/tCO2 marginal abatement cost	vs 2000	2.1%	15.0%	9.0%	71.2%	-6.2%	6.1%
	vs 2020 [Frozen]	-18.0%	-20.2%	-16.7%	-35.8%	-44.7%	-30.8%
Reduction ratio in the caste of technological reduction potentials	vs 2000	-4.8%	-2.1%	-6.7%	56.7%	-14.6%	-5.0%
	vs 2020 [Frozen]	-23.5%	-32.0%	-28.6%	-41.2%	-49.7%	-38.0%

Figure 6 Emissions in major countries and regions

Note) This result shows GHG emissions from the target sectors of this study but not all anthropogenic GHGs from all sectors.

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 5 shows sector-wise reduction potential for each region under 100 US$/$tCO_2$ marginal abatement cost in case 2. 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.

(4) Emission estimates and reduction potentials

Figure 6 shows the comparison of estimated emissions and reduction potentials in major GHG emitting countries, under the technology frozen case as a baseline, 100 US$/$tCO_2$ marginal abatement cost in case 2, and technological reduction potentials case. Before discussing the results, it is important to note that this result shows GHG emissions from the target sectors of this study but not all anthropogenic GHGs from all sectors in each region as mentioned in Figure 1 in Section 4.1.

It was found that, by introducing mitigation technologies under 100 US$/$tCO_2$ marginal abatement cost, a large amount of reduction potential can be achieved as compared to the baseline in 2020. However, due to the effects of increase of the future service demands, the emissions in 2020 still exceed the level of emissions in 2000 in major countries and regions except for India. In India, the proportion of emissions from the agriculture sector is large as shown in Figure 1 and it accounts for almost 50 % of the GHG emissions from the sectors covered in this study. Since, in case of India, in addition to the industry and power generation sectors, reduction potentials in the agriculture sector also has a large impact on the total reduction potentials, the emissions in 2020 become lower than in 2000. It was also found that, if the technological reduction potentials are taken into account, the emissions in 2020 become lower than the emissions in 2000 except in the case of China where the highest 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.

(5) Limitations of this study

Several uncertainties in the projection of mitigation potential and cost based on a bottom-up approach exist, such as in the estimates of the rate of technology development and diffusion, the cost of future technology, future energy and carbon prices, and the level of activities. These uncertainties are higher especially in developing countries due to lack of availability of reliable data.

For example, 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

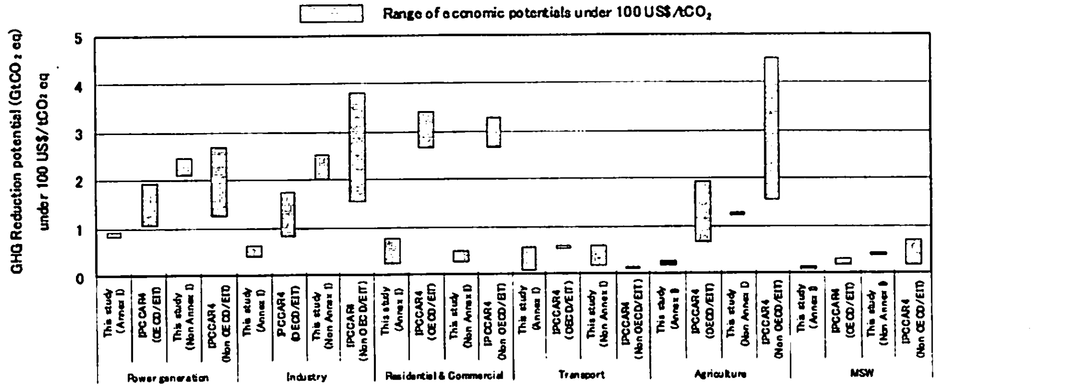


Figure 7 Comparison of this study with IPCC AR4 WG3

Note1) Results in IPCC AR4 are based on SRES B2 and IEA World Energy Outlook (2004). The results of this study are based on SRES B2, UN mid estimation, and IEA World Energy Outlook (2007).

Note2) The temporal horizon is different between this study (in 2020) and the IPCC AR4 WG3 (in 2030)

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 Figure 6. Moreover, due to the lack of data availability of technologies, some mitigation options in some target sectors were not considered in this study, for example, CO_2 mitigation options in petrochemical sector, N_2O mitigation options in chemical industry sector, and so on. Therefore, by enlarging the coverage of target sectors and mitigation options by collecting more comprehensive international data, the total reduction potentials are expected to be more than the results in this study.

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 2.2. Hence reduction potentials under the no regret case would be large as shown in Figure 4. 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.

(6) Sector-wise comparison of this study with the IPCC AR4

The IPCC Fourth Assessment Report Working Group III[2] (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 7 shows the comparison of this study 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). Figure 7 shows the range of minimum and maximum reduction potentials which are reported in Table 11.3 in IPCC AR4 WG3 and evaluated in this study with low and high discount rate cases 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 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, bio-fuel for vehicles, residential and commercial technologies such as building energy management systems, wall insulation for commercial buildings, 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.

4. CONCLUSIONS

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) Considering the difference of annual discount rate, reduction potentials of 9.0~11.5 $GtCO_2$ eq in global scale and 2.5~3.6 $GtCO_2$ eq and 6.5~7.9 $GtCO_2$ eq in Annex I and Non-Annex I countries respectively, under 100 US\$/tCO_2 marginal abatement cost in 2020, are estimated.
2) China, the United States, India, Western Europe and Russia are five major regions where there are large reduction potentials, and they account for about 60% of the total reduction potential in the world, and top ten major regions including Africa, Latin America, Middle East, Brazil and South Asia account for approximately 80 % of the total reduction potential
3) 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 Non-Annex I countries, and these sectors account for about 50% of total global reduction potential.
4) 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 emission reductions.
5) Mitigation measures of realistic and currently existing technologies under 100 US\$/tCO_2 marginal abatement cost is not enough and the emissions in 2020 still exceed the level of emissions in 2000 due to the effects of increase of the future service demands. 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 underestimates 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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* This study is the updated results based on discussions in previous studies by Hanaoka, et al.[44][45]

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