RITE GHG Mitigation Assessment Model

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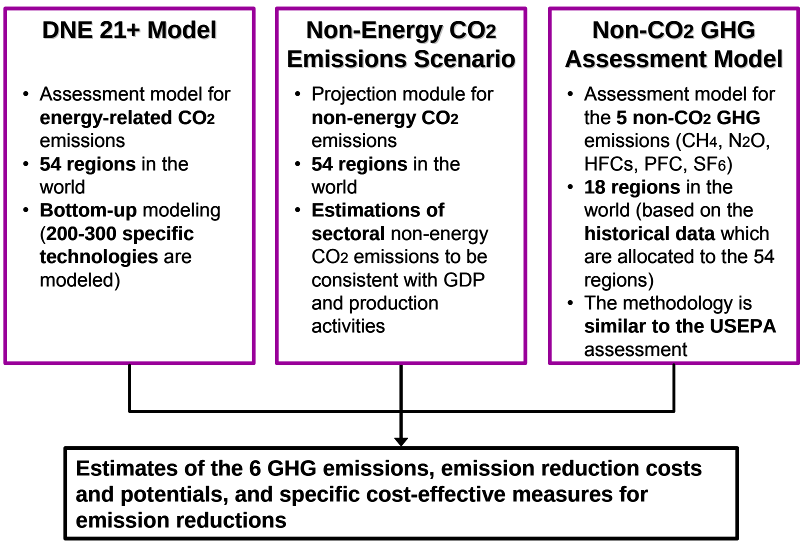
Systems Analysis Group
Research Institute of Innovative Technology for the Earth (RITE)

<Outline>

○ The model consists of 3 modules; 1) Key Assessment Model DNE21+, for energy-related CO_2, 2) Non-energy CO_2 emission scenario, that assumes specific non-energy CO_2 emissions independent of mitigation levels of energy-related CO_2 emissions 3) Non-CO_2 GHG Assessment Model, for mitigation of the 5 kinds of greenhouse gas emissions of the Kyoto Protocol.

○ The historical total GHG emissions for Annex I and Non-Annex I parties are based on GHG inventories of UNFCCC (February, 2009) and IEA Statistics (IEA, 2007a), respectively. As to energy-related CO_2 emissions, they are based on IEA Statistics for all the countries. Whereas the statistical data of Energy-related CO_2 emissions are observed to different between UNFCCC and IEA in some countries, non-CO_2 GHG emissions for Annex I parties are defined by subtracting the energy-related CO_2 emissions (IEA statistics) and the non-energy use CO_2 emissions (UNFCCC statistics) from the total GHG emissions (UNFCCC statistics), thus giving priority to the GHG emissions being consistent with the UNFCCC statistics.



I Energy-related CO_2 Assessment Model : DNE21+

1. Features

○ The DNE21+ Model represents energy systems (e.g., energy flows, capacities of energy related facilities) consistently in which the worldwide costs are minimized, when the sectoral amounts of production activities (e.g., crude steel and cement), the amount of service activities (e.g., the traffic amount in the transportation sector), the final energy demand in other sectors and the performances and the facility costs of various technologies are given.

○ When any emission restrictions (e.g., upper limit of emissions, emissions reduction targets, specific unit improvement goals, carbon taxes) are applied, the model specifies the energy systems whose costs are minimized, meeting all the assumed requirements.

○ Salient features of the model include (1) long term analysis until 2050, (2) analysis of regional differences by the fine regional segregation while maintaining other global issues consistent, and (3) detailed evaluation of global warming measures, thanks to modeled 200–300 specific technologies against global warming.

○ CO_2 from the energy sector is the principal target of evaluation.

○ The model conducts assessments for the cost minimization under the perfect foresight, and does not take into account such uncertain factors as related to energy security etc. Therefore, implications from the model analysis results should accordingly be drawn.

○ The lead time is not taken into account while construction of large-scale facilities such as electric power plants often requires a long lead time. Thus, the implications from the analysis results should be prudential.

2. Model Structure

○ Total worldwide energy system costs over all the assessment period are minimized (an optimization type linear programming model). The energy supply sectors are hard-linked with the energy end-use sectors, including energy export/import, life times of facilities, so that assessments are conducted keeping complete consistency with energy systems.

○ Eight representative time points are used for optimization: 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050 (2005 represents the period from 2003 to 2007, 2010 represents the period from 2008 to 2012, 2015 represents the period from 2013 to 2017 and so on.)

○ The world is divided into 54 regions (America, Canada, Australia, China, India, Russia are divided into further small regions, making a total of 77 regions).

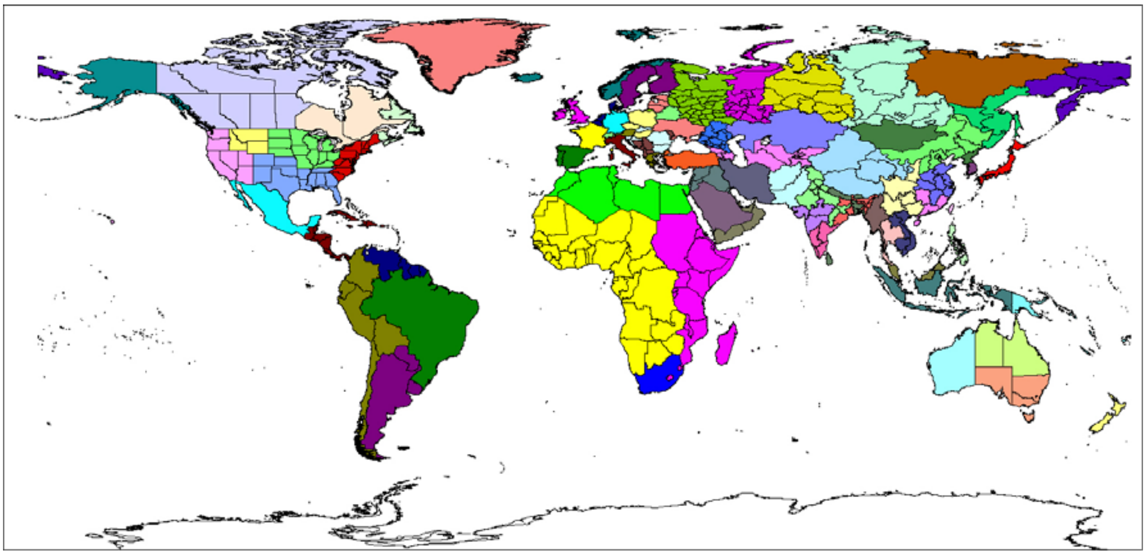


Fig.1-1 Global regional division in DNE21+

○ Technological costs and energy efficiency of energy supply technologies (various power generation technologies, oil refinery, coal gasification technology, etc.) and carbon dioxide capture, storage and sequestration are explicitly modeled ("Bottom-up approach”).

○ Energy Demand Technologies

· Costs and energy efficiencies of technologies used in energy intensive industries such as steel, cement, paper & pulp, aluminum, some groups of the chemical industry (ethylene, propylene production in the petrochemical industry and ammonia production), transportation (automobiles) and several groups of residential & commercial sector are explicitly modeled ("Bottom-up approach"). The amounts of activities of these sectors (industry: outputs, automobiles: transportation demands, groups of residential & commercial sector: time periods of equipment utilization) are estimated exogenously and kept fixed in this model regardless of emissions constraints, while technological options are endogenously determined in the model and so are energy consumption amounts etc.

- Other sectors whose technological characteristics and future evolutions vary depending on the region and, therefore, whose bottom-up modeling and incorporation into the model are assumed inappropriate and do not necessarily lead to fruitful evaluation are modeled in a top-down fashion; final energy demands are divided into four macro types (solid energy demand, liquid energy demand (gasoline demand, light oil demand, heavy oil demand), gaseous fuel demand and electrical energy demand) and their amounts of demand are assumed for aggregated three sectors: industry, transportation and household without considering specific technologies ("Top-down approach"). The assessment is carried out covering all the sectors at the same time.
- The energy-saving effects are evaluated using long-term price elasticity.

○ With the facility vintage (facility introduction year and capacity) taken into account, it is explicitly considered that cost-efficiencies of facility replacement vary depending on the representative time point and then explicitly reflected on cost-efficient technology selection. If a new facility is constructed within the life time of an old one, its cost will be high because of the cost compensation of the old facility but this option can also be examined in the model.

○ Interregional transportation of energy (coal, oil natural gas, synthetic oil, ethanol, electrical power and hydrogen) and CO_2 are incorporated in the model.

○ Eight types of primary energy are considered (coal, oil(conventional and unconventional), natural gas(conventional and unconventional), hydro power and geothermal, nuclear, wind power, photovoltaics and biomass).

○ Electricity demand is modeled so that demand-supply balance is ensured; four kinds of time periods are set based on annual load duration curves, and electricity supply follows varying loads. This enables appropriate evaluation of electricity system corresponding to the characteristics of individual power generation technologies such as the base power source, the peak power source etc.

○ Various energy conversion processes (various types of electricity generation, coal gasification and liquefaction, natural gas reforming and the like) and carbon dioxide capture, storage and sequestration (CCS) are modeled. CCS technology was excluded from the study of the regional mitigation potentials up to 2020 and evaluated with the assumption of its availability only after 2020 so that the harmonization made among the model teams of "the Mid-term Target Explanatory Council" of the government is maintained.

○ The total costs of the energy systems are the sum of the followings;

a) Costs of bottom-up individual technologies

[facilities cost]/ [payback period]+[operation and maintenance costs][1)] + [annual fuel cost]

[1)] [operation and maintenance cost] is assumed to be a certain ratio of facility costs and the annual expense rate is assumed in the individual technology as follows; [annual expense rate] ≡1/ [payback period] + [the ratio of operation and maintenance cost to facility cost].

b) Costs of top-down fields (loss of consumption utility)

As for other energy consumptions where technological options are not explicitly modeled but only final energy demands of four kinds are provided in a top-down fashion, the long-term price elasticity relationships are used representing the rapport between the final energy price and the amount of energy-saving. The integrated value of the two over the evaluation time periods can be defined as loss of consumption utility and is interpreted as the mitigation costs of top down fields.

○ Despite the high facility costs, if the energy-saving effect is high enough and the annual fuel cost is more cost-saving than the cost increase due to ([facility costs]/ [years of payback period]) of the new facility, such options of high-cost technologies are chosen in the case of 0 $/tCO_2$ marginal mitigation costs in the model. More specifically, measures considered having negative net costs are selected by the model optimization for the reference case without any emissions mitigation efforts.

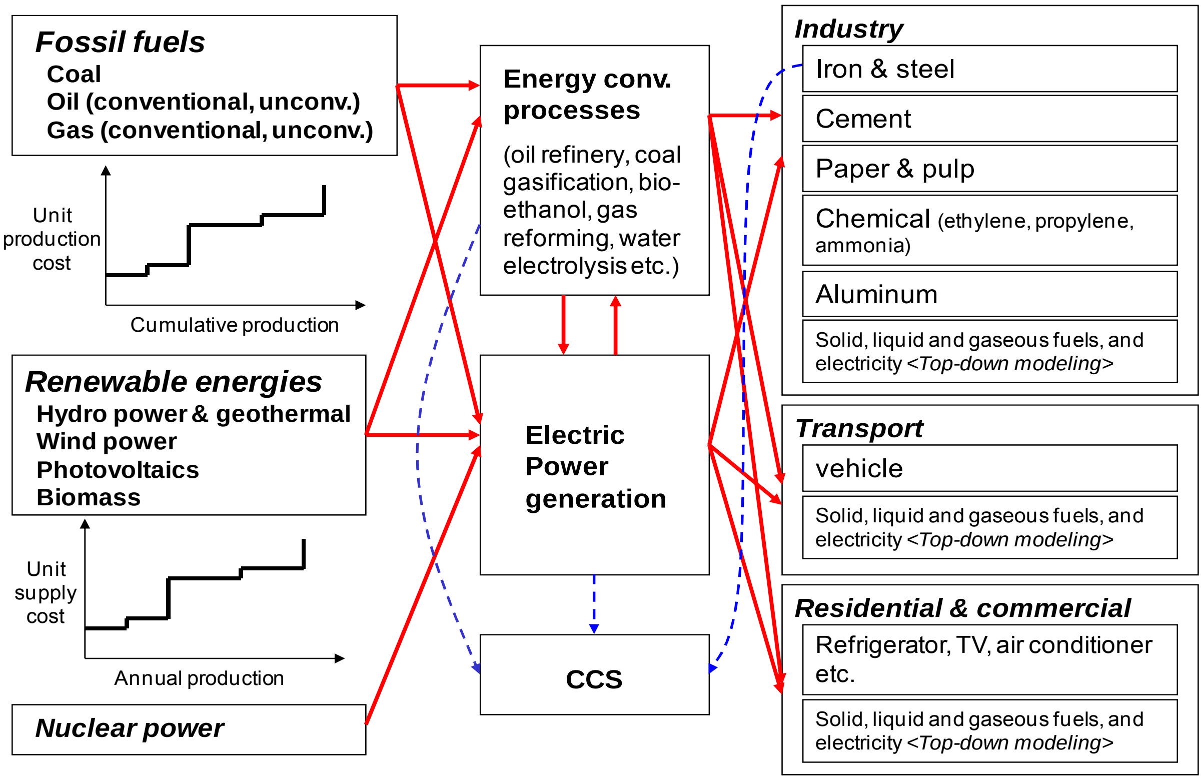


Fig.1-2 Outline of energy flows in DNE21+

Table 1-1 Bottom-upped technologies in DNE21+

Sector		Technologies
Electricity		Coal power {low efficiency (subcriticality), mid-efficiency (supercriticality), high efficiency (extra supercriticality–IGCC/IGFC), IGCC with pre-combustion CO_2 capture}, Oil power {low efficiency (diesel generator, etc.), mid-efficiency (subcriticality), high efficiency (supercriticality), CHP}, Synthetic oil power {mid efficiency, high efficiency}, Natural gas power {low efficiency (steam turbine), mid-efficiency (conventional NGCC), high efficiency (high temperature NGCC), CHP, oxy-fuel combustion}, Biomass power {low efficiency, high efficiency}, Nuclear power {conventional, next-generation (Generation IV, etc.)}, Hydro/geothermal power, Wind power, Photovoltaics, Power storage system for wind/PV, Hydrogen power, Electrical cable {conventional, superconducting high efficiency}, CCS {post-combustion capture; applicable for coal, oil, synthetic oil, natural gas, biomass power}
Industry		
	Iron and steel	BF-BOF {low efficiency (small scale), mid-efficiency (large scale), high efficiency (large scale, equipped with CDQ, TRT, recovery of by-product gases), next-generation (super coke oven, eg. SCOPE 21, utilizing plastic wastes and tire wastes, as well as highly efficient equipments), iron making by hydrogen reduction}, COG recovery {externally attachable to low/mid-efficient BF-BOF}, LDG recovery, CDQ/TRT {externally attachable to mid-efficient BF-BOF}, Direct reduction {natural gas base (mid/high efficiency), hydrogen gasification base}, Scrap-EAF {low efficiency (small scale), mid-efficiency (tri-phase electric arc furnace), high efficiency (DC water-cooled walls arc furnace equipped with scrap preheating)}, CCS {applicable for BF-BOF}
	Cement	Small scale facilities: Vertical kiln, Wet rotary kiln, Dry rotary kiln, SP/NSP dry rotary kiln {equipped with suspensionpreheaters (SP), or new SP (NSP) meaning precalciner}, Advanced fluidized bed shaft furnace {equipped with SP/NSP, efficient clinker coolers} Large scale facilities (more efficient than small scale): Wet-process rotary kiln, Dry-process rotary kiln, SP/NSP dry-process rotary kiln, SP/NSP dry-process rotary kiln (BAT) {equipped with efficient clinker coolers, SP with 5 or 6 levels, efficient waste heat recovery}
	Pulp and Paper	Chemical pulp {low efficiency, mid-efficiency, high efficiency, next-generation}, Paper recycling {low efficiency, mid-efficiency, high efficiency}, Milling paper {low efficiency, mid-efficiency, high efficiency, Next-generation}, Black liquid recovery&use {low efficiency, high efficiency}, Paper sludge boilers, Steam turbine power systems
	Aluminum	Söderberg aluminum production, Prebake aluminum production
	Chemical	Ethylene/propylene: Naptha cracking {low efficiency, mid-efficiency, high efficiency, next-generation}, Other production {ethane cracker etc. low efficiency, mid-efficiency, high efficiency} Ammonia: from Coal {low efficiency, mid-efficiency, high efficiency}, from Oil {low efficiency, mid-efficiency, high efficiency}, from Natural gas {low efficiency, mid-efficiency, high efficiency}
Transportation		Types: Small passenger car, Large passenger car, Bus, Small truck, Large truck Internal combustion engines (gasoline/diesel) {conventional internal combustion cars (low/high efficiency), hybrid cars, plug-in hybrid cars}, Electric cars, Fuel-cell cars, Alternative fuels {bioethanol mixed with gasoline, biodiesel mixed with diesel, CNG}
Residential & Commercial		Refrigerator {low efficiency, mid-efficiency, high efficiency}, Lighting {small bulb, small fluorescent light, small next-generation (LED etc.), medium size mid-efficient fluorescent light, medium size high-efficient fluorescent light, medium size next generation (LED, OLED etc.), large size mid-efficient HID, large size high-efficient HID, large size next-generation (LED etc.)}, Television {small size low efficiency, small size high efficiency, large size low efficiency, large size high efficiency, large size next generation (high-efficient liquid crystal television, plasma, rear projection, OLED)}, Air conditioner {low efficiency, mid-efficiency, high efficiency}, Gas cooking stove {low efficiency, mid-efficiency, high efficiency}

3. Assumed Key Conditions

The model is established under a number of assumed conditions. The followings are key assumed conditions.

3.1 Assumed Population and GDP

○ Population statistics and prospects from United Nations 2006 are used. (UN, World Population Prospects: The 2006 Revision. http://esa.un.org/unpp/)

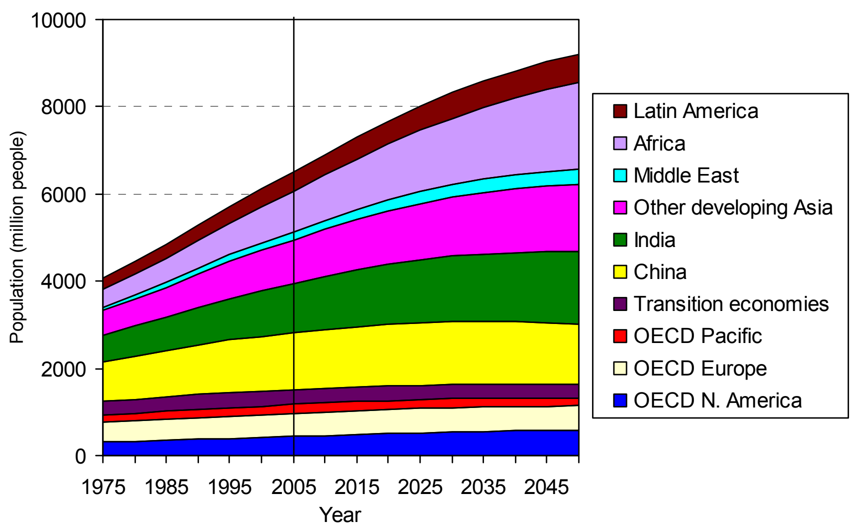


Fig.1-3 Population projections

○ GDP growth rates of the world and major countries were prepared by Japan Economics Research Center for Mid-term Target Exploratory Council in December 2008. Based on them, GDP scenarios were made for the 54 regions.

○ From 2030 to 2050, GDP growth rates for the four regions in the IPCC SRES B2 scenario (OECD90, former Soviet Union and Eastern Europe, Asia, Other) were referred and per-capita GDP growth rates were estimated for the 54 regions.

○ Average annual rates of GDP growth from 2005 to 2020 are the followings; 1.3% for Japan, 1.9% for US, 1.9% for EU27, 5.0% for Russia, 8.2% for China, 7.2% for India, and 3.0% for the whole world.

○ Population and GDP are not directly utilized to assume conditions for the energy model but to assume the amount of production/service activities for individual sectors with bottom-upped technologies and also energy demands (IEA, 2007b) for other sectors of top-down approach without specific technology bottom-up.

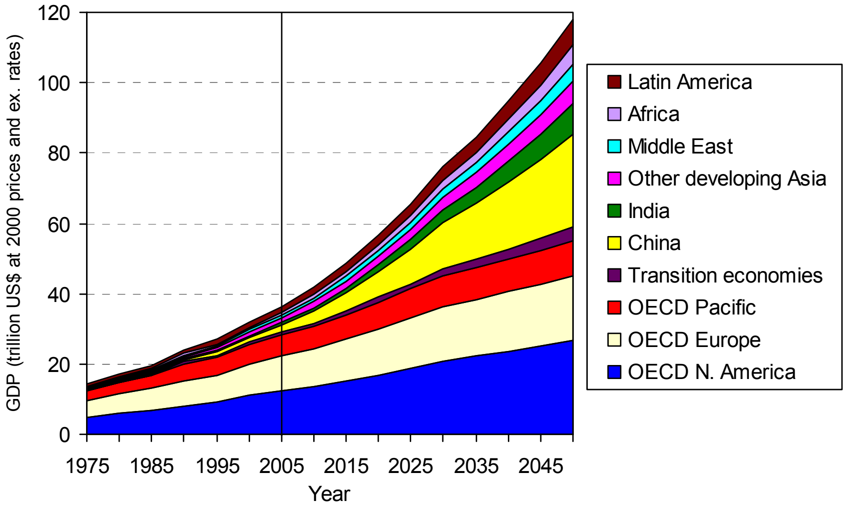


Fig.1-4 GDP projections

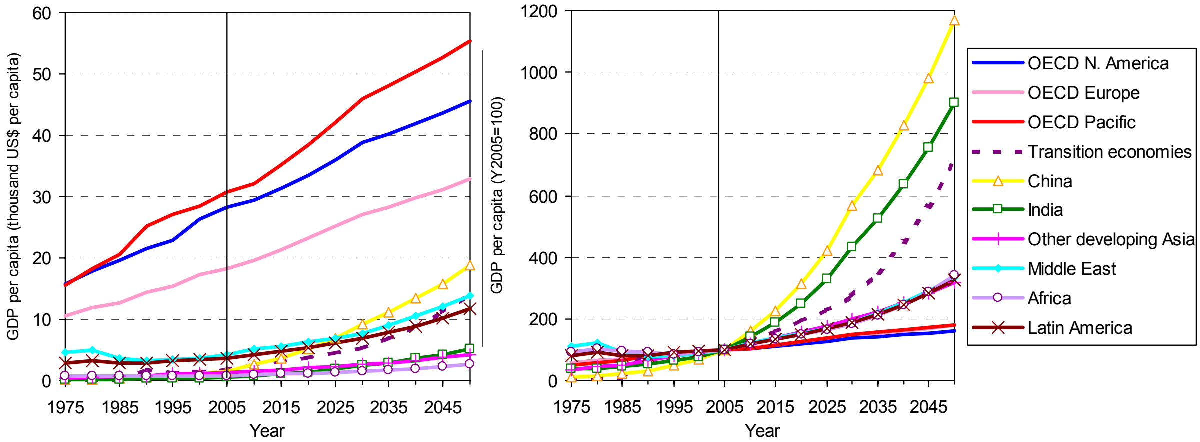


Fig.1-5 per capita GDP projections

3.2 Assumed Production/ Service Activities

(1) Iron and steel sector

○ The correlation between evolution of per-capita GDP and per-capita apparent consumption of crude steel, trends in industry structure change by region, government planning reports etc. were taken into account in the scenario construction.

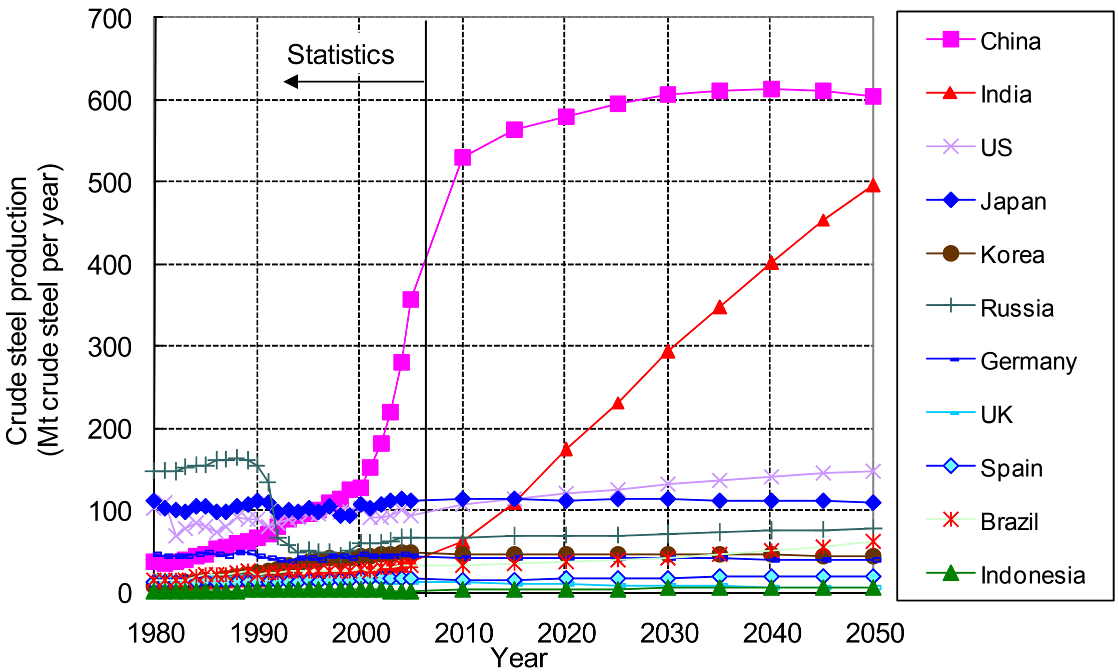


Fig.1-6 Crude-steel production of major regions (statistics and future scenario)

(2) Cement sector

○ Cement production scenario is assumed from historical trends based on the following assumptions; 1) when the regional per-capita GDP is low, the cement production depends on the total GDP. 2) when per-capita GDP is high, the production depends on the population size.

○ The clinker/cement ratio is fixed across the timeframe of analysis.

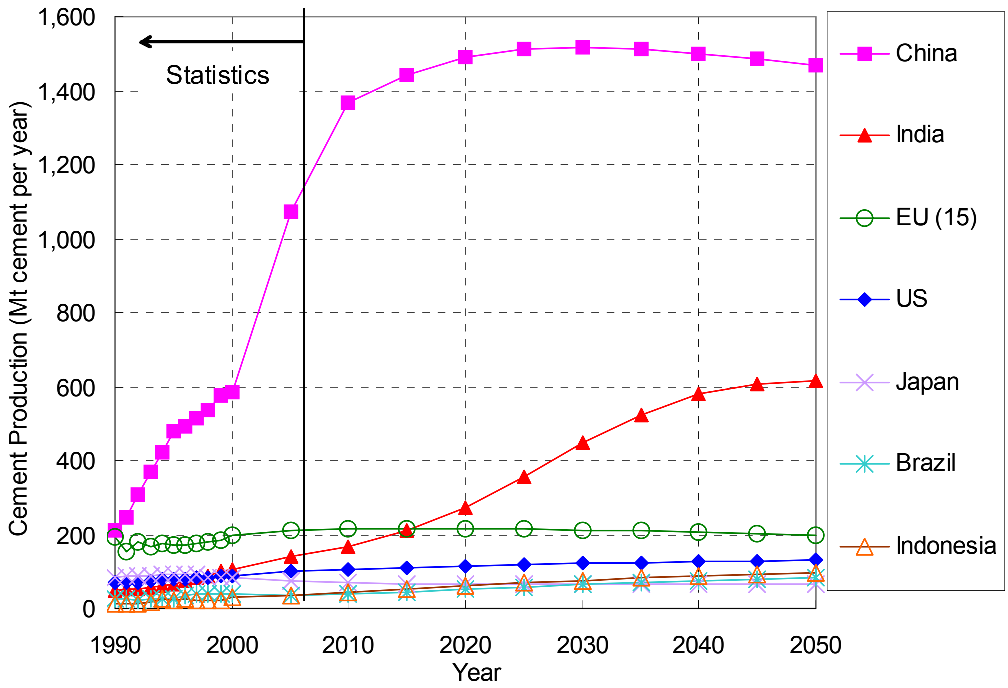


Fig.1-7 Cement production of major regions (statistics and future scenario)

(3) Transportation sector

○ Road passenger transport (p-km) scenarios for passenger cars and buses are separately assumed based on per-capita GDP and the historical trends. Also the transition of modal share is assumed. (Fig. 1-8)

○ As for road freight transport (t-km) scenarios for cargo trucks, overall cargo service per-capita is estimated by the GDP size, and then the transition of modal share is assumed. (Fig. 1-9)

○ As for transportation scenarios in Japan, the traffic service is assumed based on the updated prospect by National Land and Transportation Ministry.

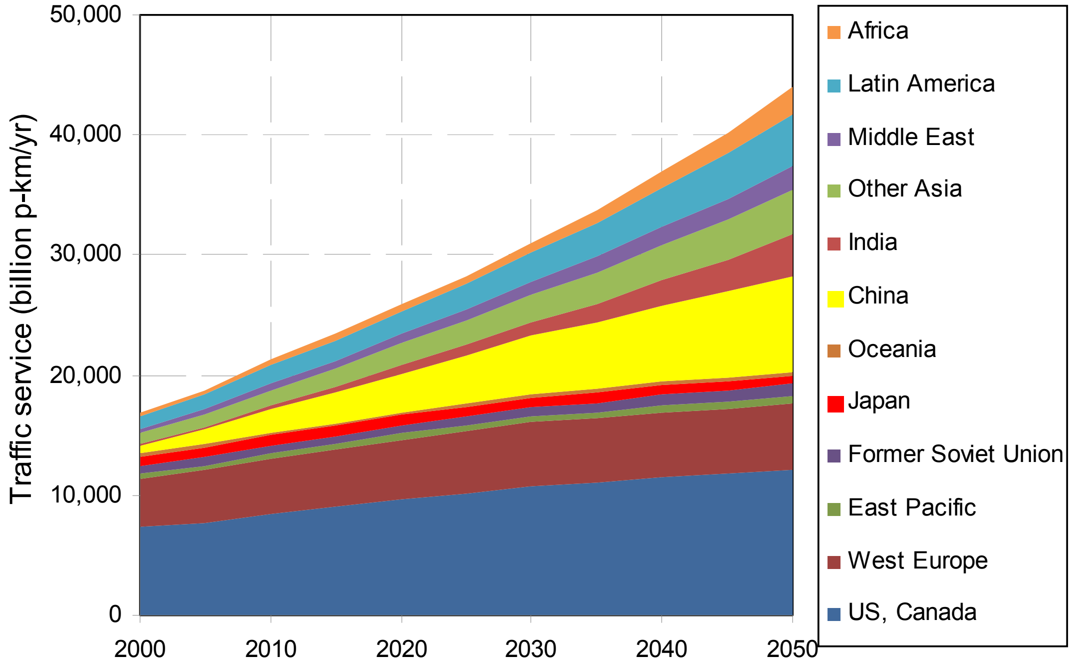


Fig.1-8 Traffic service of passenger car by region

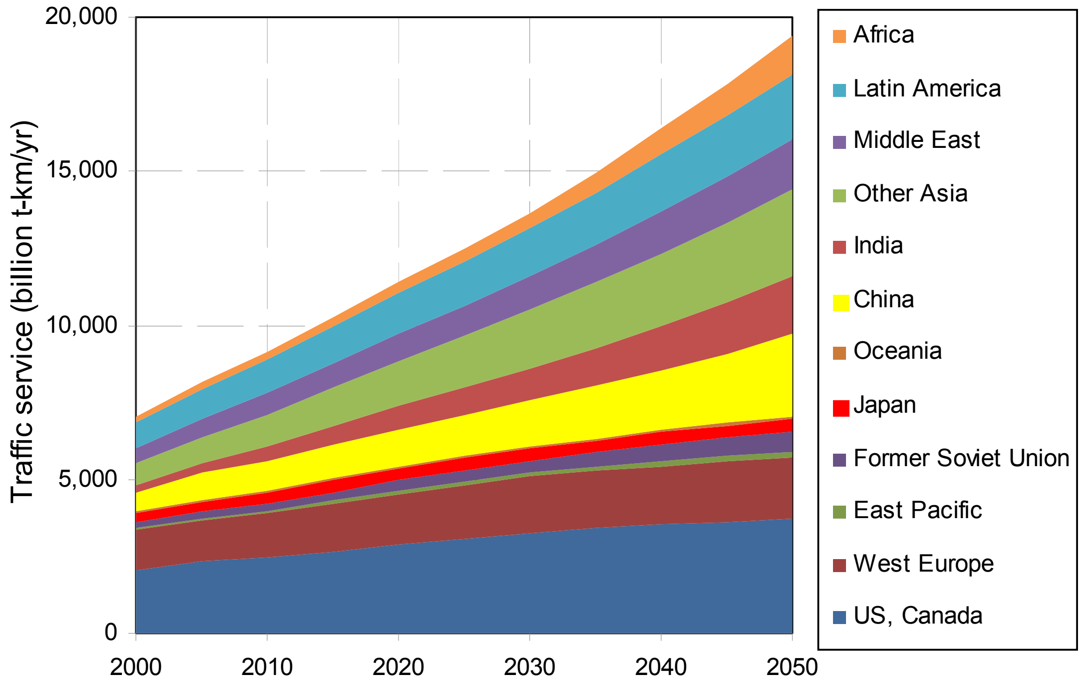


Fig.1-9 Traffic service of cargo truck by region

3.3 Facility Introduction

(1) Iron and steel sector

○ The crude steel production scenario is modeled by sorting out the processes into three routes; basic oxygen furnace (BF-BOF), scrap-based electric arc furnace (EAF) and DRI-based electric arc furnace (DRI-EAF) where the estimation on the historical installation of the facilities are conducted and their results are taken into account; installation year, energy efficiency and capacity. Fig.1-10 shows the estimated energy efficiency of BF-BOF by region at 2000 (specific energy consumption).

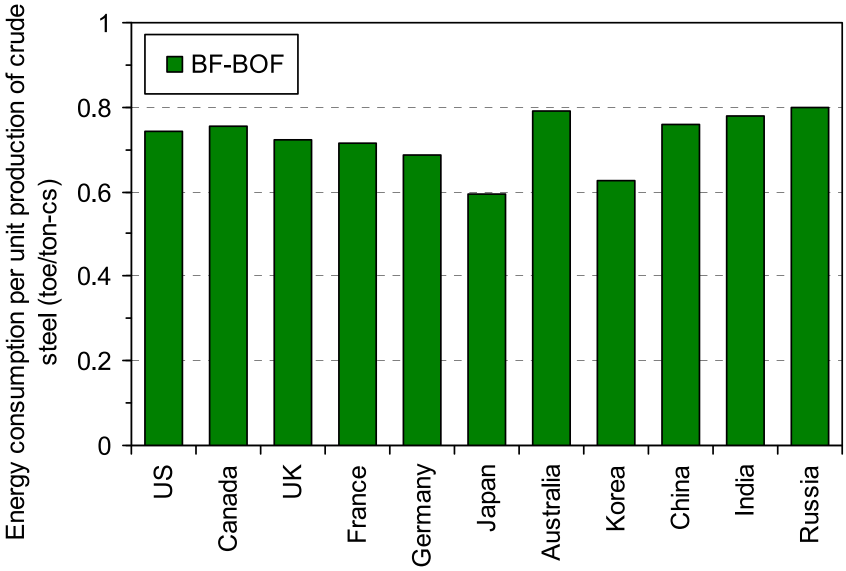


Fig.1-10 Estimated energy efficiency by region

Note 1) The less energy consumption is, the higher energy efficiency is

Note 2) Electricity is converted to primary energy using 1MWh=0.086/0.33 toe

(2) Cement sector

○ The model is also constructed with the estimation of the historical installation of the facilities; installation years, energy efficiencies and capacities of the facilities. Fig1-11 shows the energy efficiency calculated for the cement production and clinker production by region at 2000 (specific energy consumption).

○ The more adulterated clinker is, the higher the energy efficiency (per ton of) cement production is, and the cement qualities vary by region. As discussed above, the clinker/cement ratio is fixed by region across the timeframe of analysis.

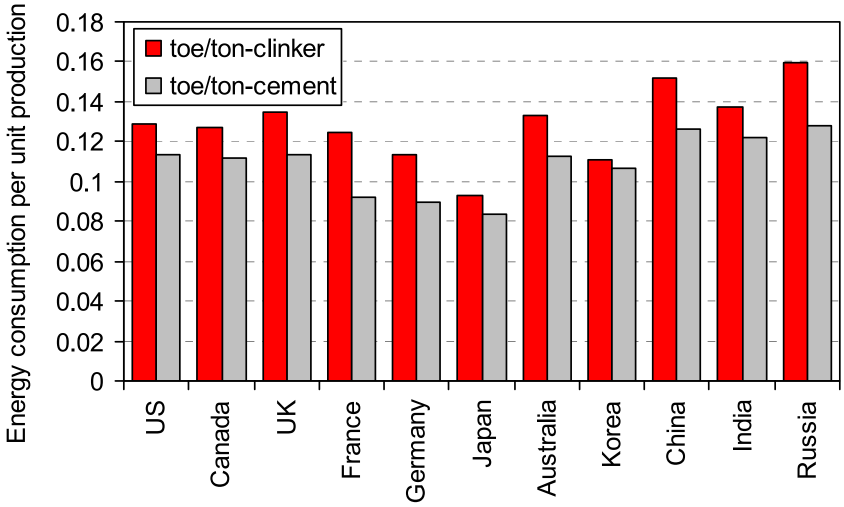


Fig.1-11 Estimated energy efficiency by region

Note 1) The less energy consumption is, the higher energy efficiency is

Note 2) Electricity is converted to primary energy 1MWh=0.086/0.33 toe

(3) Electricity generation sector

○ The model is constructed based on the estimation of the historical installation of the facilities; installation years, energy efficiencies and capacities of the facilities. Fig.1-12 shows the regional efficiency of power generation by fossil fuels.

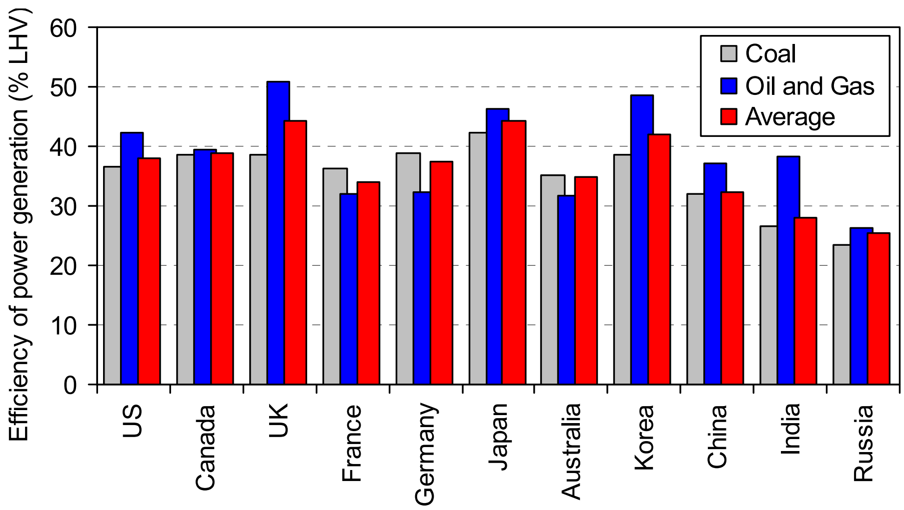


Fig.1-12 Efficiency of power generation by country in 2005

Note) The higher efficiency rate is, the higher energy efficiency is

3.4 Assumed Payback Period

○ The payback period is calculated from numerous kinds of factors observed in the society such as interest rate, income and financial leeway, subjective preference for risk, and prospective profit rate of stockholders. In business behavior, the return on investment (ROI) is generally 10–20%, and this means that payback period has to be 5–10 years. Table1-2 shows the assumed payback period, considering such situations.

○ In the analysis by International Institute for Applied Systems Analysis using GAINS model (IIASA, 2008), an international research similar to ours, the discount rate is determined 20% across the board in the standard case, corresponding to a 5 year payback period. In the TIMER model of Netherlands Environmental Assessment Agency, the payback period is assumed to be 1–3 years (de Vries et al., 2001).

Table 1-2 Assumed payback period

	Payback period	
	Upper limit	Lower limit
Electricity generation sector	10	6.7
Other energy conversion sector	7	4.7
Industrial sector (energy-intensive industry)	10	6.7
Transportation sector	5	3.3
(Purchase of environment-conscious products)	(10)	
Residential & commercial	3	2.0

Note) Payback periods are assumed within the above list for the regions depending on their per capita GDP

Note) The upper limit is applied for Japan

3.5 Wind Power and Photovoltics

○ Wind power and photovoltaics is assumed to have an annual costs decrease rate of 1.0% and 3.4%, respectively. In 2000, the unit costs of wind power is 56–118$/MWh and photovoltaics 209–720$/MWh, depending on wind velocity and solar radiation etc. In 2050, the unit costs of wind power and photovoltaics are assumed to become 34–71$/MWh and 37–128$/MWh, respectively.

○ Since the peak of wind power generation does not always match the instantaneous peak time period of power demand, the output of wind power generation at instantaneous peak time is assumed to be 30% of the maximum capacity of wind power generation. Since the power generation time period of photovoltaics is limited, power supply is assumed to be possible only during the instantaneous peak time and the peak period of time.

○ From the viewpoint of stability of the power system, the maximum useable amount of power generation by wind power and photovoltaics is each assumed to be 15% of total power generation. However it is assumed that use of storage batteries may expand the upper supply limit by 15% to total 30%. Wind power with storage batteries is assumed to account for up to 60% of maximum output during instantaneous peaks. When storage batteries are used in association with photovoltaics, power supply is possible during medium demand periods in addition to instantaneous peaks and peaks. The water electrolysis for hydrogen production by photovoltaics has no upper limit, (naturally restrictions on supply of natural resources should be treated separately).

3.6 Nuclear Power Generation

○ Exogenous scenarios are assumed for nuclear power generation up to 2030. (Table 1-3)

○ Some constraints are assumed that the power generation of nuclear would be capped at 50% of the total power generation amount and that an annual expansion of conventional nuclear power generation would be 0.33%, and the expansion rate of advanced nuclear power generation would be 1%. As long as the constraints are obeyed, costs-efficient options are selected by the model.

Table 1-3 Scenarios for nuclear power generation (TWh/yr)

	2005	2020
Japan	305	437
United States	811	873
EU27	987	965
Russia	149	346
China	53	282
India	17	124
Worldwide total	2767	3677

4. Model Simulation Results

(1) Regional CO_2 emission outlook

○ If CO_2 emission intensity stayed the same in the future (if global warming mitigation were not advanced in the future), the CO_2 emissions of the entire world would double the current emissions in 2020.

○ There are large potentials for emission reductions of negative costs, and these potentials should be implemented. Yet, barriers need to be removed and large efforts are required to bring the potential into practice.

○ High emission growth in Non-annex I countries are estimated for the future.

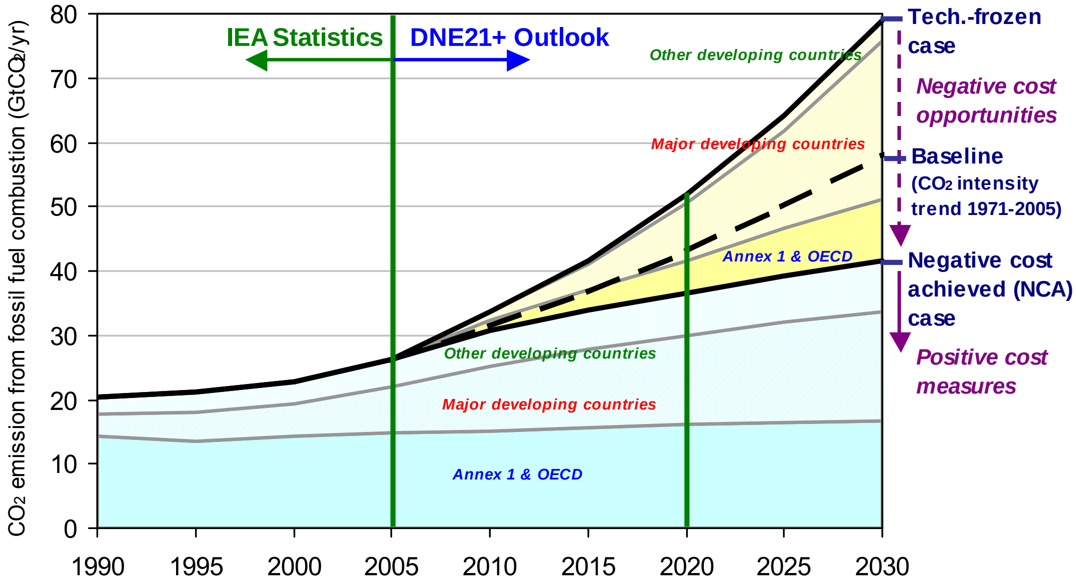


Fig.1-13 the world CO_2 emission prospect

(2) Estimated regional potentials for emission reduction

○ There are large potentials for emission reductions of negative costs and relatively low costs (<20 \$/tCO_2).

○ Reduction potentials of United States below 20 \$/tCO_2 have a large share in those of Annex I & OECD.

○ Reduction potentials of China and India below 20 \$/tCO_2 have large shares in those of major developing countries.

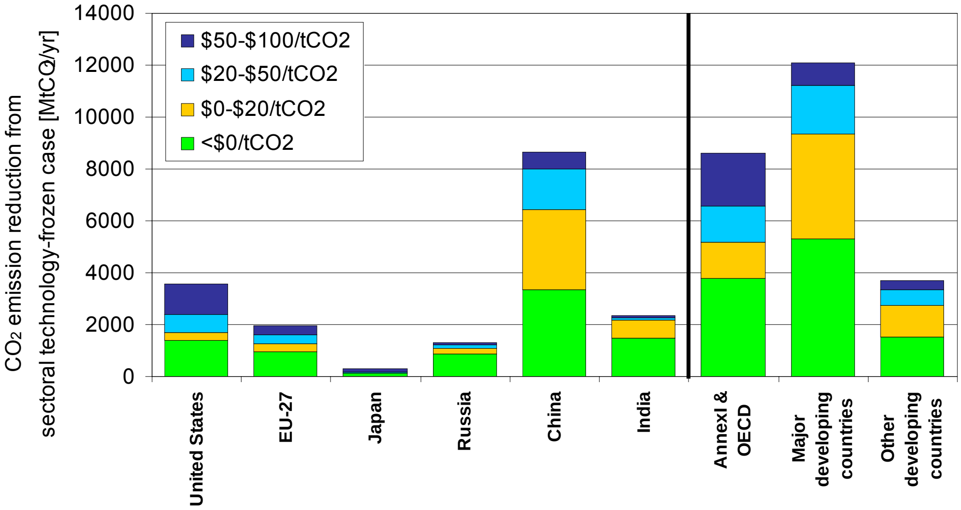
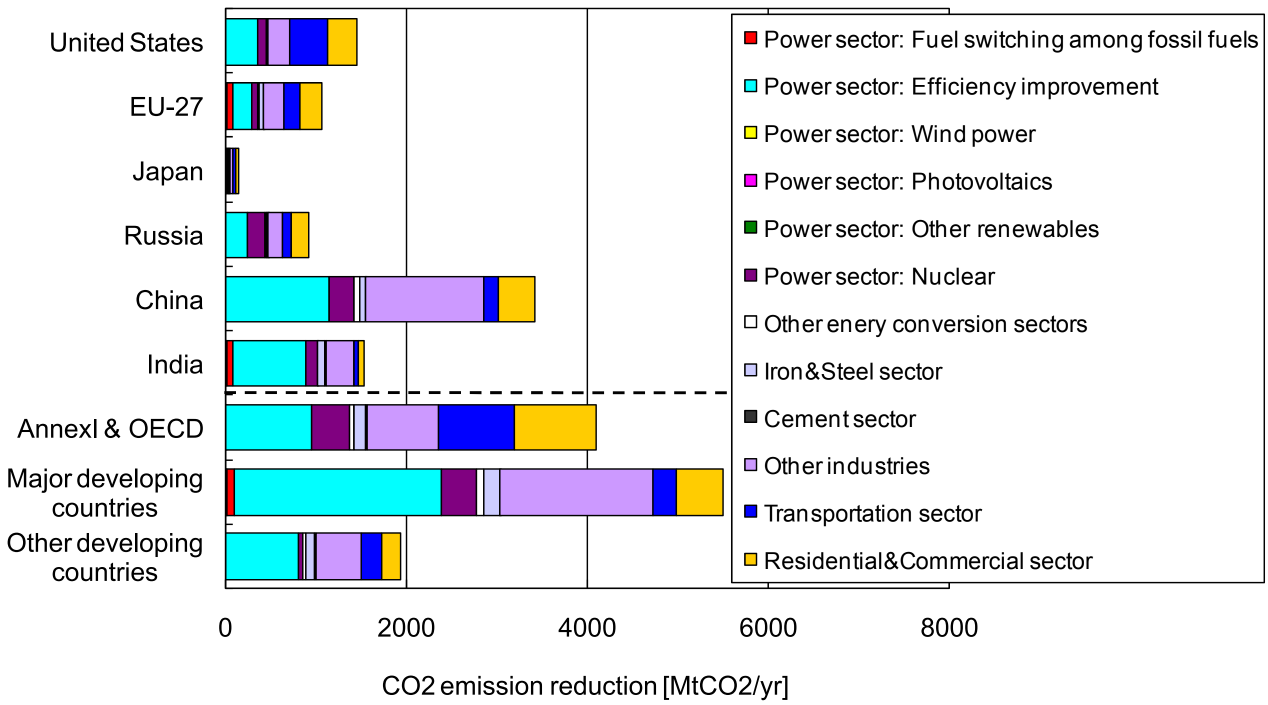


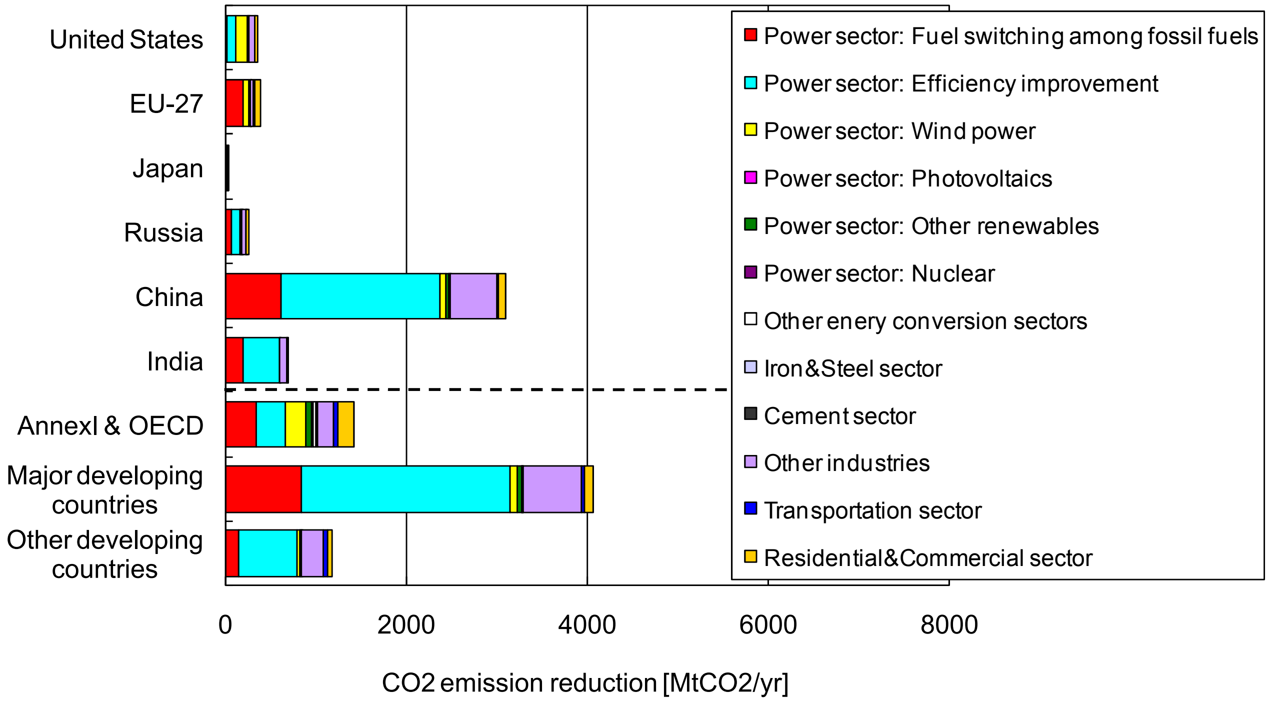
Fig.1-14 Regional emission reduction potentials by marginal costs in 2020

○ Fig.1-15 shows potentials for sectoral and regional emission reduction in 2020.

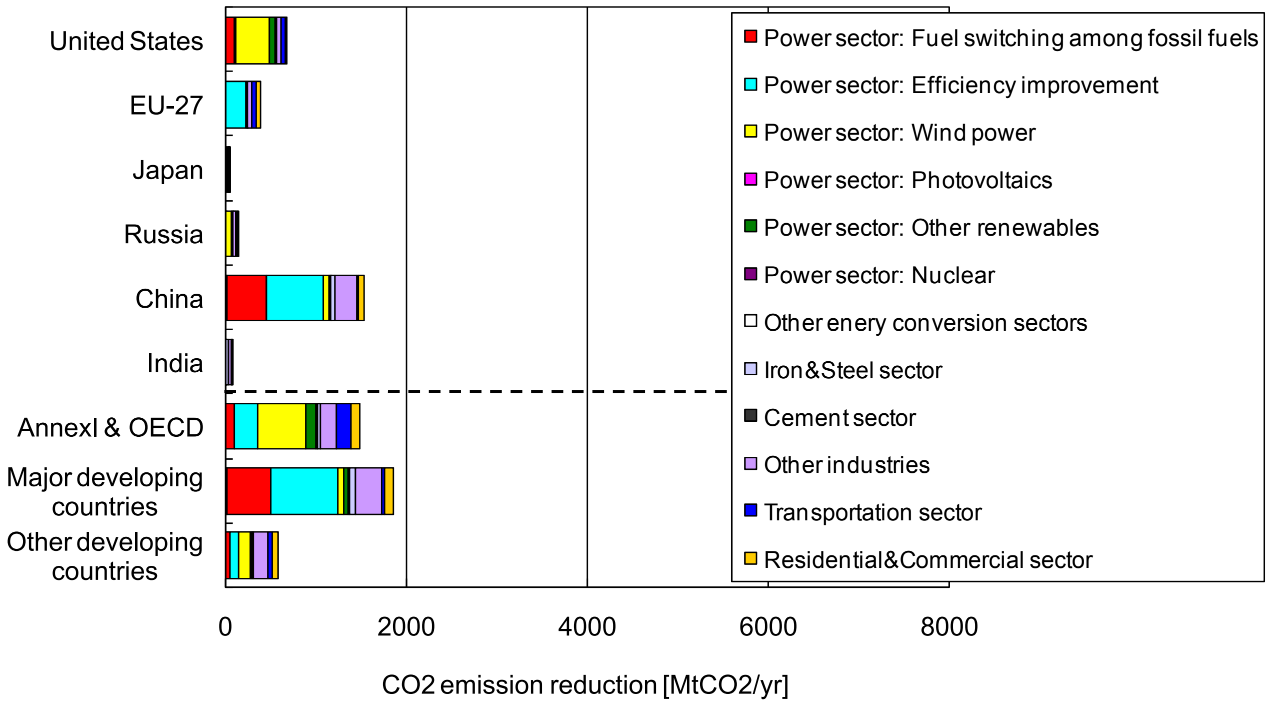
(a) ≤ 0$/$tCO_2$



(b) 0–20$/t CO_2



(c) 20–50$/t CO_2



(d) 50–100$/t CO_2

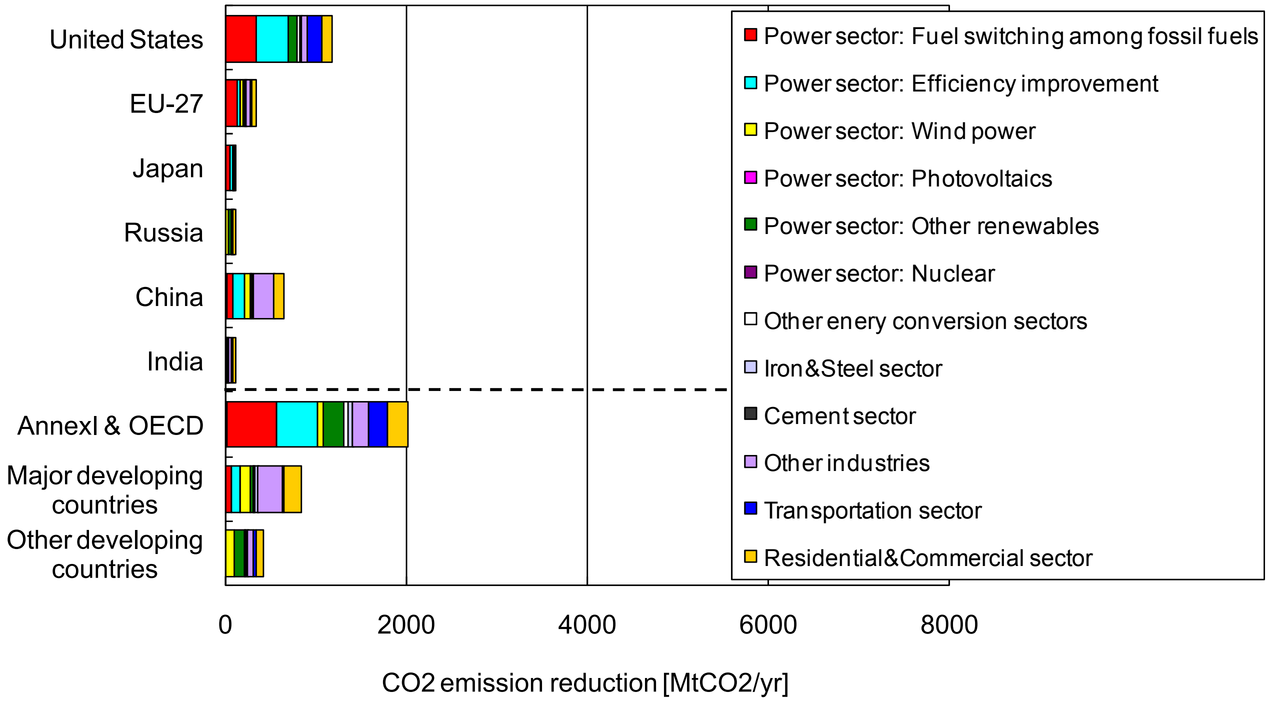


Fig. 1-15 Sectoral emission reduction potentials by region in 2020

Note) Emission reduction effects by switching from coal power to gas combined power are divided and allocated to [Power sector: efficiency improvement] (as gas combined power is generally more efficient than coal power) and [Power sector: fuel switching among fossil fuels].

○ Compared to EU27 and the United States, Japan is observed to have smaller mitigation potentials. However, there are several other countries which are observed to have small mitigation potentials in terms of the mitigation ratio relative to 1990 such as some of EU member countries and Canada, as well as Japan.

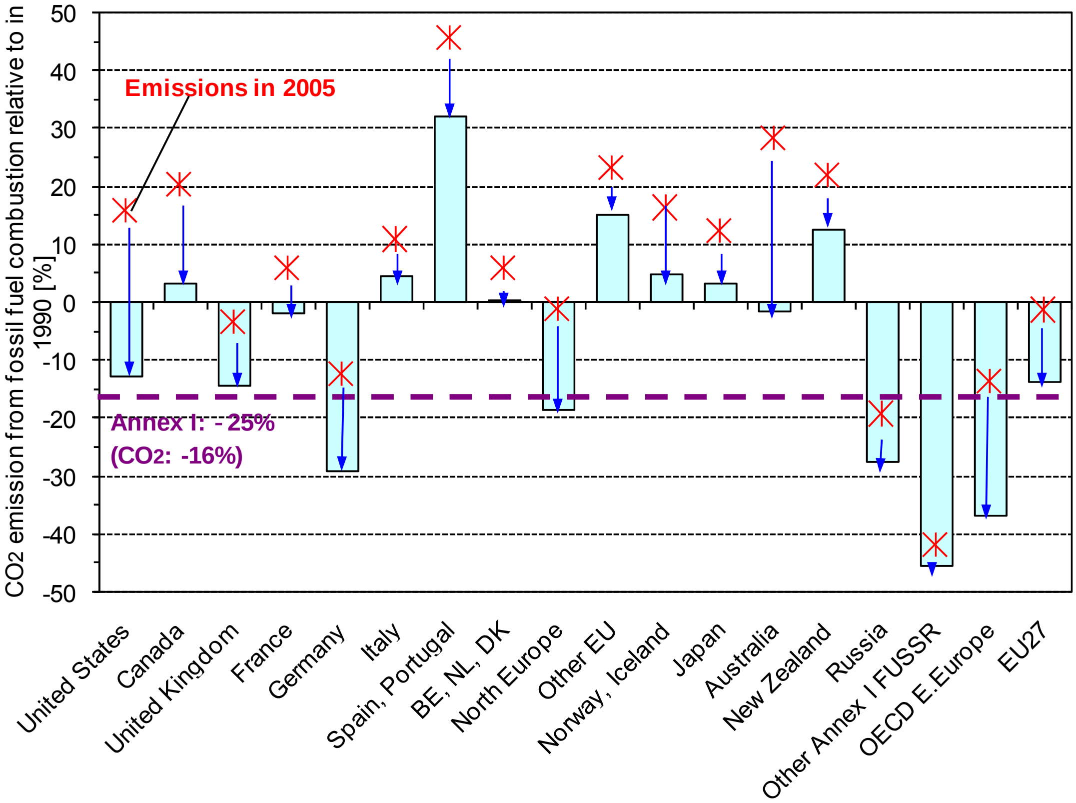


Fig.1-16 CO_2 emissions in 2020 in case of equalization of marginal abatement costs: GHG emission reduction in Annex I by 25% relative to 1990 levels (energy CO_2 ;16% reduction)

(3) Estimation of energy supplies in the world regions

○ As to the primary energy consumption, the higher the marginal mitigation costs are, the more the energy is saved. Also, the shares of natural gas and renewable energy are increased.

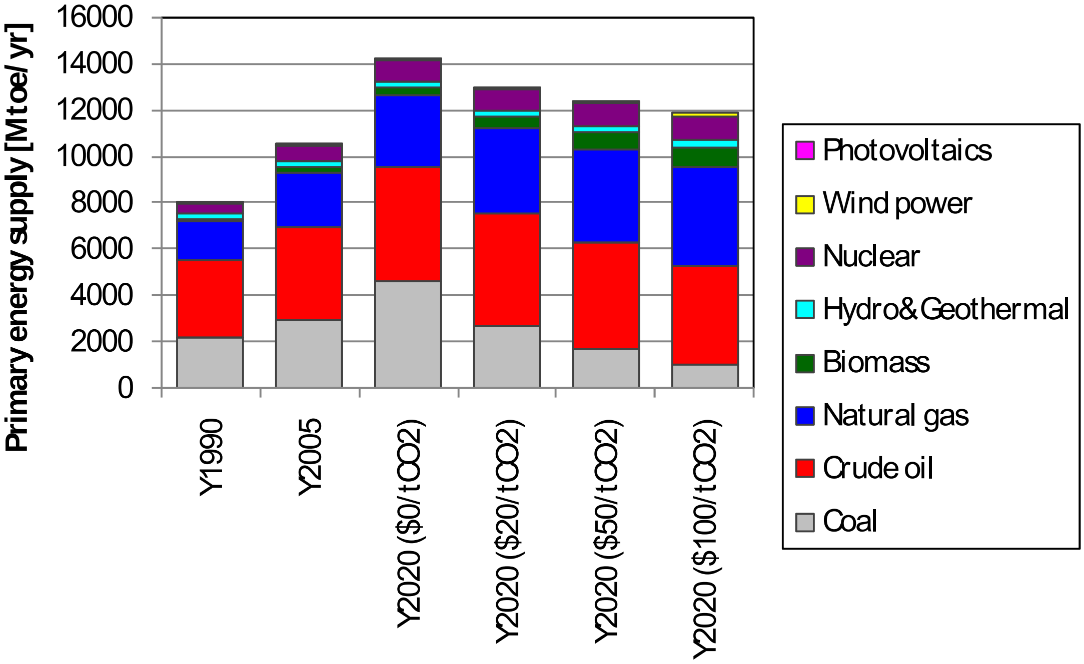


Fig.1-17 World primary energy consumption by marginal costs in 2020

II Non-Energy CO_2 Emissions

1. Overview

○ Exogenous scenarios which stay fixed regardless of individual mitigation options are assumed. The followings are reasons.

<Regarding “fugitive”>

- Measures are already in progress to reduce flares.
- References relating to cost analysis for flare reductions are not necessarily satisfactory.

<Regarding industrial processes>

Cement sector

- Expansion of blended cement sale would enable to decrease the clinker to cement ratio. However, the blended cement requires a longer curing time and it can not necessarily meet all the demanded requirements. It seems difficult to decrease the clinker ratio by policy induction.
- In principle, using fly-ash as clinker feedstock would enable to reduce limestone. However, there is a social barrier that this makes difficult to accept (take) other waste materials.
- Application of CCS to kiln exhaust gas will enable to reduce CO_2 emissions from the production processes. However, a large amount of application of CCS is unreasonable and impractical, considering the high cost push-up ratio to the cement cost and financial constraints observed generally in cement industries to say nothing of those in the developing countries.

Iron and steel sector

- Measures of CCS are impractical, since CO_2 emissions are dispersed across the various processes in plants

<Regarding waste>

- In consideration of social demands of both CO_2 emission reductions and appropriate disposals of waste, it seems hard to take measures only for CO_2 emission reductions.

2. Estimation method of CO_2 emissions

○ Non-energy CO_2 emissions are estimated for the future, using sectoral approach and the following methodology.

○ CO_2 emissions from 1990–2005 were based on UNFCCC data (2009) for Annex I parties, and IEA Statistics (IEA, 2007a) for Non-Annex I parties.

<Regarding “fugitive”>

“Fugitive” is CO_2 emissions generated when hydrocarbon gas is burned as flare in oil wells or gas fields. The amount of flare depends on the regional characteristics of geology or measures of effective use of and backfilling into underground of the hydrocarbon gas and not on oil or natural gas production output.

Accordingly, CO_2 – fugitive for the future is estimated simply, assuming that the historical trends will continue in the future. This estimation means that the past efforts including effective utilization of and backfilling of the gas will continue in the future. (In some regions, the increasing rate of fugitive emissions is extremely high. In cases like this, the upper limit of the increasing rate is set 2% p.a.)

<Regarding industrial processes + waste>

According to the industrial processes data of UNFCCC, emissions from cement and aluminum sectors are very strongly associated with cement and primary aluminum production, respectively. As for 0.5 gas emissions from these sectors, emission scenarios for the future are based on the cement and aluminum production scenarios, assuming that the existing relationship will be sustained in the future.

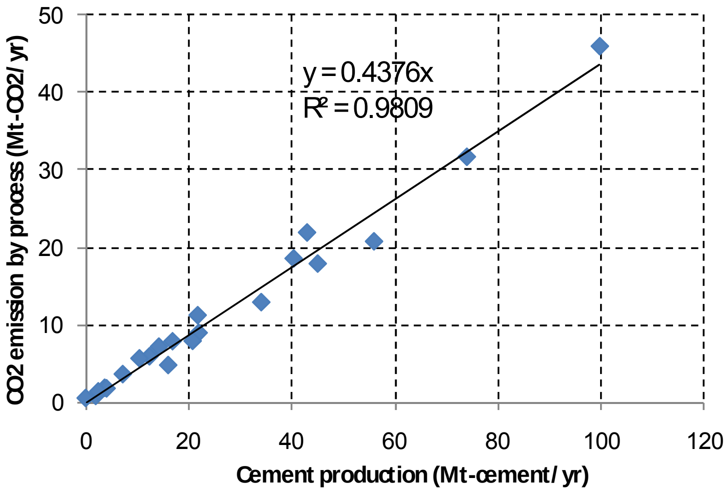


Fig2-1 Cement production and CO_2 emissions by process in 2005

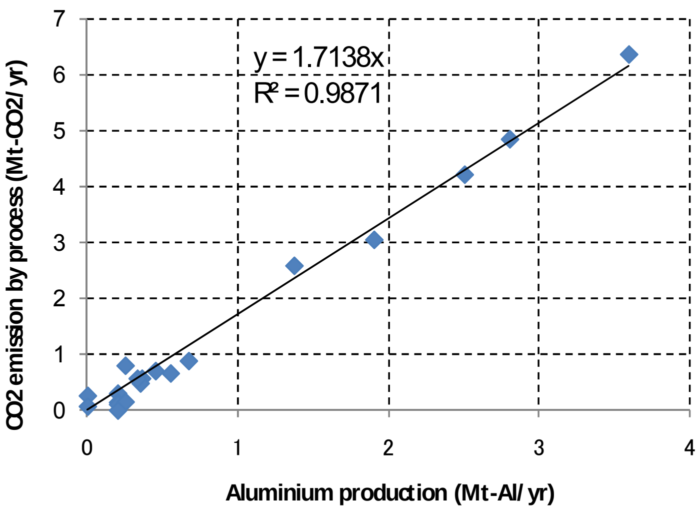


Fig2-2 Aluminum production and CO_2 emissions by process in 2005

As factors of emissions from the industrial processes + waste of other sectors than cement and aluminum sectors are various and are affected significantly by regional and specific circumstances, the detailed analysis is difficult using the existing statistics. Consequently, the industrial processes + waste emission scenarios (except cement and aluminum sectors) are generated so that the scenarios may reflect the regional circumstances, assuming the dependence on the crude steel production which may represent the "entire physical production in industrial sectors", and also assuming the regional circumstances (residuals which can not be represented by crude steel production) will continue to stay.

3. Emission scenario

Figs. 2-3 and 2-4 show the overview of non-energy CO_2 emission scenarios. Basically, in Annex I countries, the increase of raw material production, such as cement and aluminum productions is assumed to be moderate in the scenario. Accordingly, the increase in the non-energy CO_2 emission scenario is gradual (or plateauing, reduced). Canada has the highest increase rate in the developed countries, significantly affected by the increase in fugitive emission caused by oil (including unconventional oil) and natural gas production. Developing countries such as China and India are assumed to increase raw material productions and generally have sharp increases in non-energy-related CO_2 emissions in the scenario.

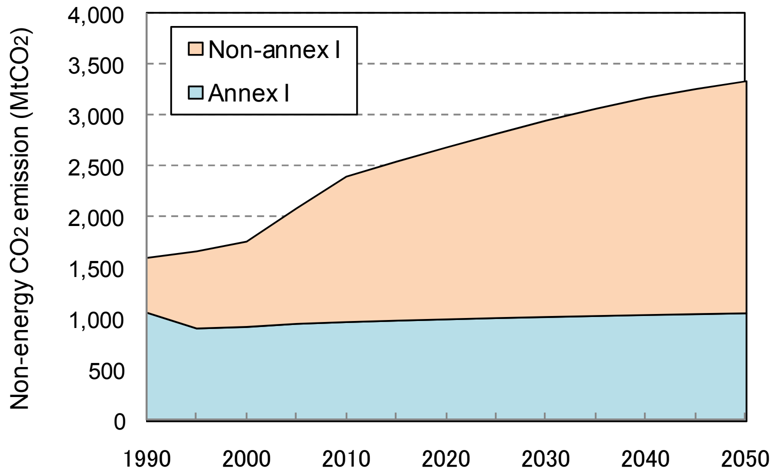


Fig.2-3 Non-energy CO_2 emissions up to 2050

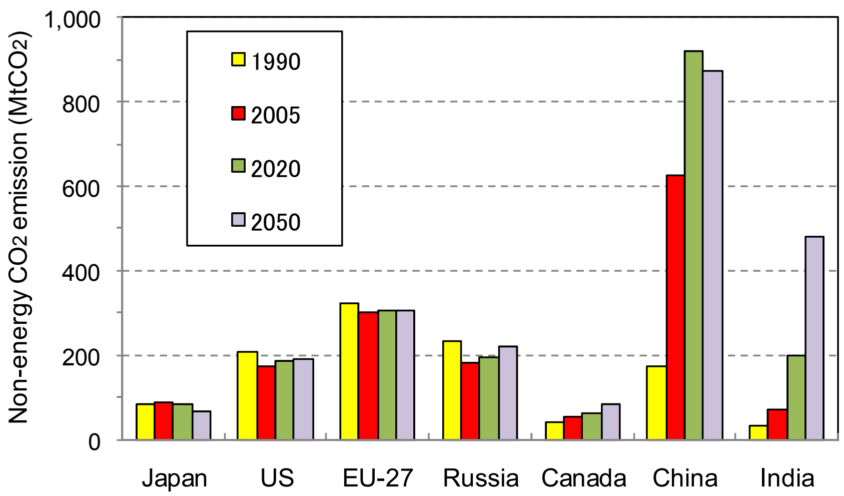


Fig.2-4 Comparison of non-energy CO_2 emissions of 1990, 2005 historical data and the 2020, 2050 scenarios

III Non-CO_2GHG Assessment Model

1. Overview

In RITE non-CO_2 GHG Assessment Model, the baseline emissions are estimated and the emission mitigation costs and mitigation potentials can also be assessed. The model considers five kinds of emissions: CH_4 (7 sectors), N_2O (6 sectors), HFCs (1 sector), PFC (1 sector), SF_6 (1 sector) in 18 regions. To be consistent with the 54 regions in DNE21+ Model for analyses of energy CO_2, the historical data of emissions in the base year are used and allocated to the regions. Basically, the model is based on USEPA analysis and assessment model (EPA(2002), EPA(2006)), although the historical data are updated.

Meanwhile, the total of GHG emissions are based on the data of UNFCCC (February, 2009) for Annex I parties, and IEA statistics for Non-annex I parties. (For more details, please refer to the top page of this document.)

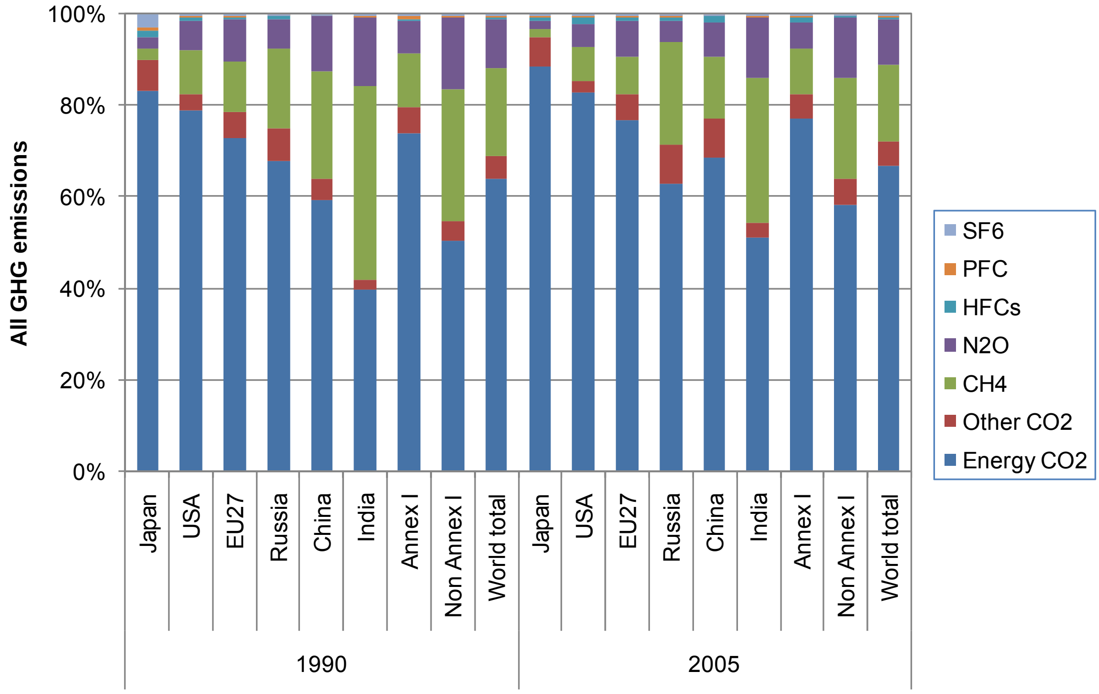


Fig. 3-1 Shares of all GHG emissions by region

Note) Annex I countries are from UNFCCC data, Non-annex I countries from IEA data

2. Estimation of baseline emissions

CH_4 emissions are considered in 7 sectors: agriculture, oil, coal, natural gas, residential and transportation, energy intensive industries, and other industrial sectors. N_2O emissions are considered in 6 sectors: agriculture, oil, natural gas, residential and transportation, energy intensive industries, and other industrial sectors. HFC_S, PFC and SF_6 are considered in one-macro sector each. The sectoral baseline emissions are estimated in the following way.

<CH_4 from the agriculture sector>

The agriculture sector is divided into 6 groups: rice cultivation, grassland burning, agricultural residue burning, enteric fermentation, livestock manure, land use change and each group is estimated by region. Methane baseline emission from rice cultivation is estimated according to the population of the relevant regions, based on EPA estimation methods. Emissions from grassland burning are estimated based on Masui (2001) and assumed that they vary depending on the meadow areas in IPCC SRES-B2 scenario. In this case, the FAOSTAT data (FAO, 2002) are used for the regional meadow areas for the base year. Emissions from agriculture residue burning are estimated similarly to those from grassland burning, assuming that they vary depending on the cultivation areas in SRES-B2 scenario. Emissions from enteric fermentation are estimated based on EPA estimation methods and also on the grazing areas, numbers of livestock and the livestock production ratios. Emissions from enteric fermentation are estimated, keeping fixed emission intensity in accordance with the IPCC guideline (IPCC, 1996). But due to large uncertainties of land use, the estimation is adjusted to be nearly consistent with the EPA estimation up to 2020. As for emissions from livestock manure, the baseline is estimated similarly to those from enteric fermentation and based on the grazing areas, numbers of livestock and the livestock production ratios. Emissions from land use change, which may naturally be assumed to come from burnt or rotten biomass waste, are estimated to be in inverse proportion to the conversion of grazing and forest areas in the SRES-B2 scenario.

<N_2O from the agriculture sector>

Emissions from 7 groups are estimated by region; emissions from soil plus the same 6 groups as CH_4 emissions from the agriculture sector. N_2O emissions from the aforementioned 6 groups of the agriculture sector are estimated, using the same methods as for CH_4 from the agriculture sector. As for N_2O emissions from soil, the total of 4 kinds of emissions are estimated; those from chemical fertilizer, nitrogen-fixing plants, crop residues and others. The future emissions from chemical fertilizer are estimated using the exponential regression formula of nitrogenous fertilizer production, using time, population and GDP per capita as explanatory variables, and also considering the estimation methods of Tilman (2002), Masui (2001) and USDA (2003). As for nitrogen-fixing plants, future production of soybeans and edible seeds are estimated, using the future projection data of FAOSTAT (FAO, 2005) and IFPRI (IFPRI, 1999) up to 2015. After 2020 the baselines are estimated using the data of areas under cultivation in the SRES-B2 scenario, assuming that the crop yields will vary according to the areas under cultivation. The emissions from crop residues are estimated from rice and oats plus the nitrogen-fixing plants mentioned above. Emissions from others are estimated by multiplying the numbers of aforementioned livestock by the N_2O emission specific unit of nitrogen contained in livestock manure. However, due to large uncertainties, the estimation is adjusted to be nearly consistent with the EPA estimation up to 2020.

< CH_4, N_2O from the oil, coal and natural gas sectors >

The estimated baselines of oil, coal, and natural gas sectors are based on GDP per capita and the EIA estimations of production and estimation scenarios, respectively, to be coherent with the EPA methods.

< CH_4, N_2O from the residential & transport sector>

Emissions from 3 groups of transportation, landfills and sewerage are considered. As for transportation, the baseline is estimated based on GDP per capita and the EIA estimation of production and demand scenarios for transport, being coherent with the EPA methods. As for landfills and sewerage, being coherent with the EPA methods, the baselines are estimated based on GDP per capita scenario.

<HFCs, PFC, SF_6>

Regional baseline emissions are estimated based on the SRES-B2 4 regional emission scenario, and regional allocation is made according to regional GDP shares.

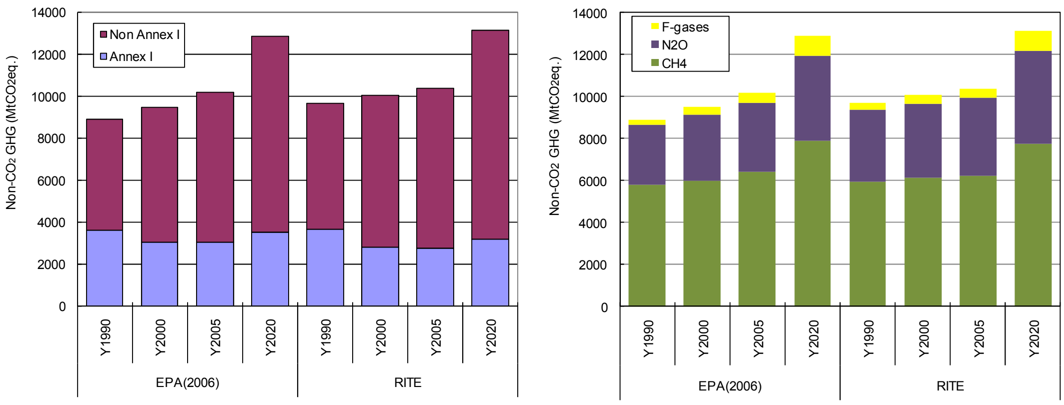


Fig. 3-2 Non-CO_2 GHG emission baselines of 2020
(left; Annex I and Non-annex I, right; by gas)

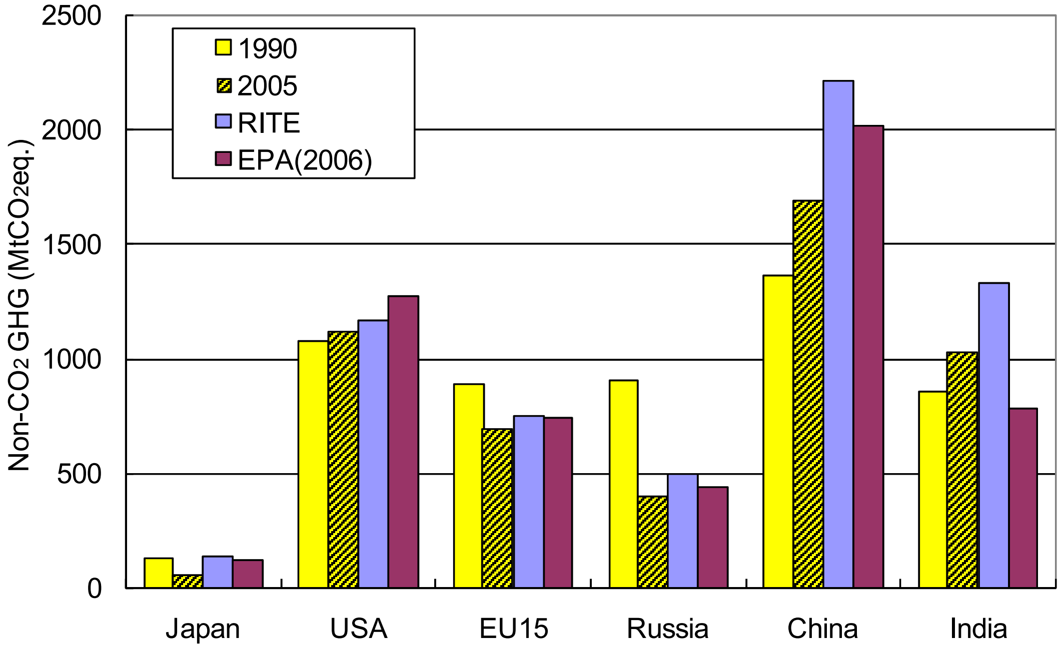


Fig.3-3 Non-CO_2 GHG emission baselines of 2020 by major region (Annex I countries are from UNFCCC data, Non-annex I countries from IEA data for historical data of 1990 and 2005, RITE estimation)

3. Estimation methods of emission reduction potentials

The assessment model for non-CO_2 GHG mitigation potentials is based on the assessments by EPA (2002), EPA (2006), and Hyman et al. (2002). Equation (3-1) indicates the relationships between the individual non-CO_2 GHG mitigation ratio and marginal abatement costs by the elasticity of substitution. This model estimates non-CO_2 GHG mitigation in 18 regions when the non-CO_2 GHG abatement costs are equalized to the CO_2 marginal abatement costs. The elasticity is determined so that the marginal abatement costs curves correspond to EPA studies by sector and gas calculated using technology database concerning non-CO_2 GHG measures. It is not a direct bottom-up model but basically its marginal costs and potentials are derived from technological bottom-up analysis by EPA.

The elasticity of Hyman et al. (2002) is basically applied to RITE model, but the elasticity is adjusted to be consistent with the analysis result for 20%/yr discount rate, in consideration of the sensitivity analysis results of the discount rate (payback period) carried out by EPA (2002). The elasticity is also adjusted in consideration of the mitigation effect report by EPA (2006) in part. Hereby, the elasticity of gases and the mitigation potentials are estimated to be smaller than those of Hyman et al. (2002).

$$\mathrm{Red\_r}(g,h,n,t) = 1 - \left(\frac{1}{P(g,h,n,t)}\right)^{\sigma(g,h,n)} \tag{3-1}$$

g: gas, h: sector, n: region, t: year

Red_r(g,h,n,t): reduction rate in total emission

P(g,h,n,t): marginal abatement cost

σ: elasticity based on EPA(2002), EPA(2006), and Hyman et al.(2002)

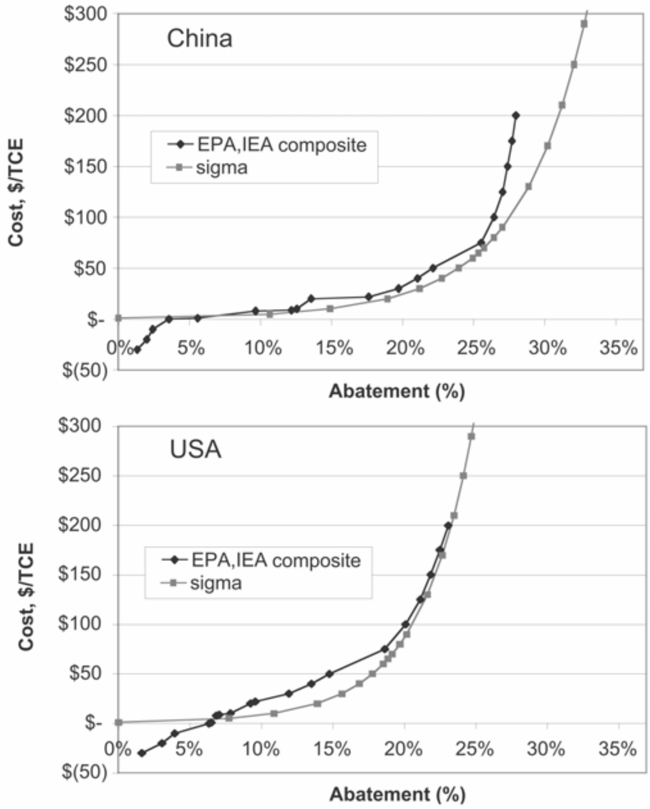


Fig3-4 Comparison of EPA parameterization (squares) with methane marginal abatement curves (diamonds) for China (top panel), and the USA (bottom panel)

Source: Bottom-up mitigation curves were derived by combining data from IEA (1998, 1999) and U.S.EPA (1999); for details see Hyman (2002)

Table 3-1 Elasticity, ‘σ’ of equation (3-1) in case of discount rate of 20%/yr

Non-CO_2	Sector	Japan	US	EU
CH_4	Agriculture	0.04	0.05	0.04
	Oil	0.00	0.04	0.02
	Natural gas	0.14	0.12	0.10
	Coal	0.59	0.29	0.08
	Final demand	0.20	0.19	0.15
	Energy intensive industries	0.11	0.11	0.11
	Others	0.11	0.11	0.11
N_2O	Agriculture	0.02	0.05	0.03
	Oil	0.00	0.00	0.00
	Natural gas	0.00	0.00	0.00
	Final demand	0.00	0.00	0.00
	Energy intensive industries	0.37	0.37	0.37
	Others	0.00	0.00	0.00
HFCs		0.03	0.03	0.03
PFC		0.15	0.15	0.15
SF_6		0.29	0.29	0.29

As for CH_4 emissions from the agriculture sector, they contain emissions from rice cultivation and domestic livestock (ruminants). For rice cultivation, the mitigation options include full midseason drainage, shallow flooding, off-season straw, use of ammonium sulfite and upland rice. Measures against CH_4 emissions from enteric fermentation of livestock include feed improvement, antibiotics and bovine somatotropin control. As for N_2O emissions from the agriculture sector, emissions from cultivated soil accounts for a large share. The mitigation options are available such as separated application of nitrogen fertilizer, reduction of fertilizer application and no-tillage. In agriculture, the assumed regional parameters are required to reflect regional situations since soil, aqueous environment and climate conditions vary depending on the regions. However, substantial mitigation which inevitably accompanies cost increase is practically very hard, as it has a large impact on food supply as well as cost increase. Thus, a relatively low elasticity is assumed than other sectors. As developed countries have little potentials for the future increase of agricultural products, the baseline emissions are assumed to be nearly constant for them since the basic year, 2005.

CH_4 emissions from the energy sector include 1) methane emissions in coal mining

2) methane emissions in mining, storage and transportation of natural gas 3) methane emissions associated with oil refinery. As for 1), the reduction options include CH_4 capture from coal mines, catalytic oxidation of VAN (ventilation air methane) from coal mines, flaring methane emissions, electric generation by captured methane and so on. As for 2), enhanced management of aging facilities in natural gas systems is included as an option. As for 3), flaring and direct reduction can be assumed in oil refinery. Emissions from this sector are very little in Japan. Russia emits most of CH_4 from natural gas systems among developed countries. Consequently, this sector has large mitigation potentials and, to be precise, large mitigation potentials of CH_4 from energy sector for a whole Annex I parties.

CH_4 emissions from the residential & transportation sector include emissions from landfills, wastewater and sewage. Since the measures for them are relatively facile and corresponding CDM project activities have been implemented in developing countries, a large elasticity is assumed also in developed countries. In this model, mitigation options of N_2O emissions from wastewater and sewage are not considered.

N_2O emissions from the energy-intensive sectors arise mostly from the production of nitric acid and adipic acid. Mitigation potentials from the baselines are considered as large as those in Hyman et al. (2002). The major mitigation options include emission control equipments, process improvement and pyrolysis.

HFC emissions increased rapidly from 1990 to 2005 in developed countries except Japan and foam insulation utilization grow in the future in many countries including Japan. Correspondingly, emission growth in baselines is assumed to be high. As HFC mitigation options include gas replacement, gradual decrease of emissions caused by leakage in the process of production/disposal/collection/reuse/destruction, aerosol gas replacement (only dust blowers in Japan), recovery/leakage prevention(improvement of capture ratio and leakage ratio) of commercial air conditioning and refrigeration equipments, gas replacement of detergent and solvent. Japan has little room of mitigation as 100% recovery has already been accomplished for car air-conditioners and vending machines, and so assumed for Japan.

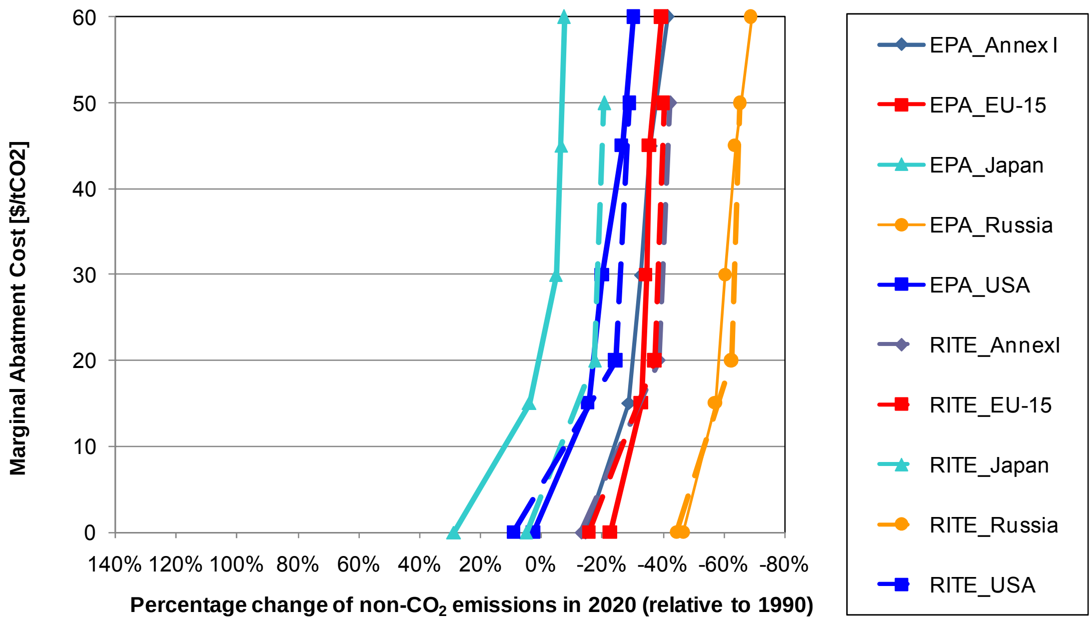
As for mitigation of PFC and $SF_{6,}$ reduction effects by installation of decomposition devices are projected in the future and so assumed. The United States and Japan already reduced substantial SF_6 of the electricity sector by the time point of 2005 and their baseline emissions are assumed not to grow substantially in the future.

4. Estimated Emission Reduction Potentials

Fig.3-5 shows RITE and EPA (2006) analyses of non-CO_2 GHG emissions reduction relative to base years by marginal reduction costs for major regions in 2020 relative to 1990 and 2005. Fig.3-5 a)(relative to 1990) shows considerable differences among the regions, but Fig.3-5 b) (relative to 2005) shows only little differences. Furthermore, Fig.3-5 a) shows considerable differences between RITE and EPA results as for Japan. This disagreement is due to the fact that EPA uses much smaller values of emissions for 1990 than the historical data reported by UNFCCC while they use larger values for 2005 than the corresponding UNFCCC data whereas RITE makes a fairly good adjustment to meet the UNFCCC historical data.

Fig.3-6 shows emissions by marginal abatement cost and by region. Mitigation potentials are observed fairly large up to 50 $/t$CO_2$ for all the regions while they are small beyond this value.

a) Emissions relative to 1990



b) Emissions relative to 2005

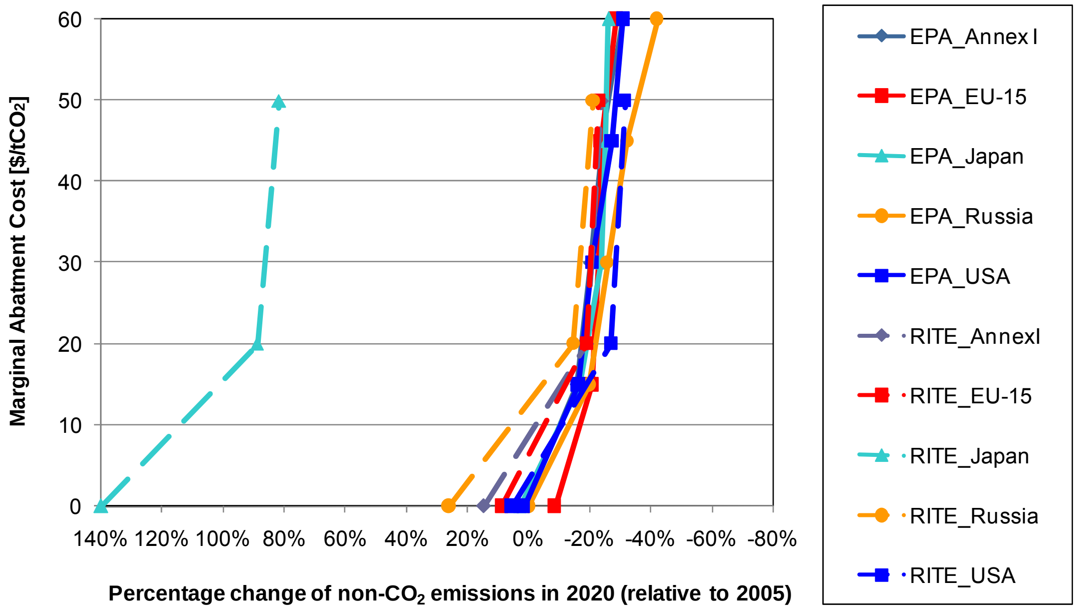


Fig. 3-5 Comparison of marginal costs of non-CO_2 GHG emissions of 2020 relative to different base years in EPA and RITE model

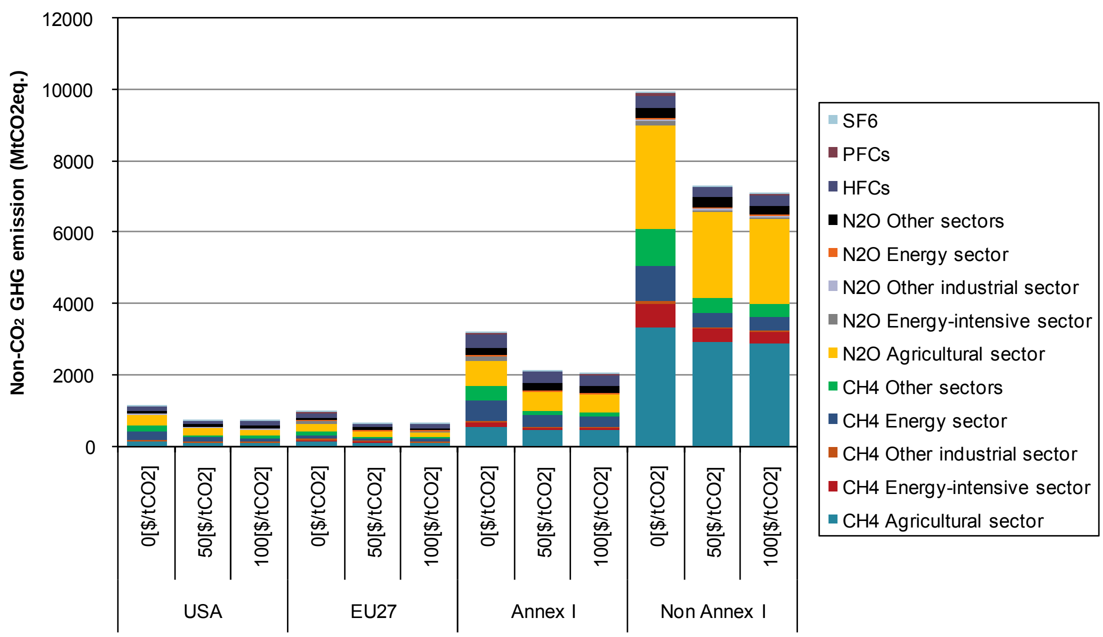


Fig. 3-6 Non-CO_2 GHG emissions of 2020 by marginal abatement cost and by region

IV Summary of Analyses by RITE GHG Mitigation Assessment Model: Marginal Abatement costs in Annex I parties

1. Marginal abatement costs curves in 2020 based on 1990 GHG emissions

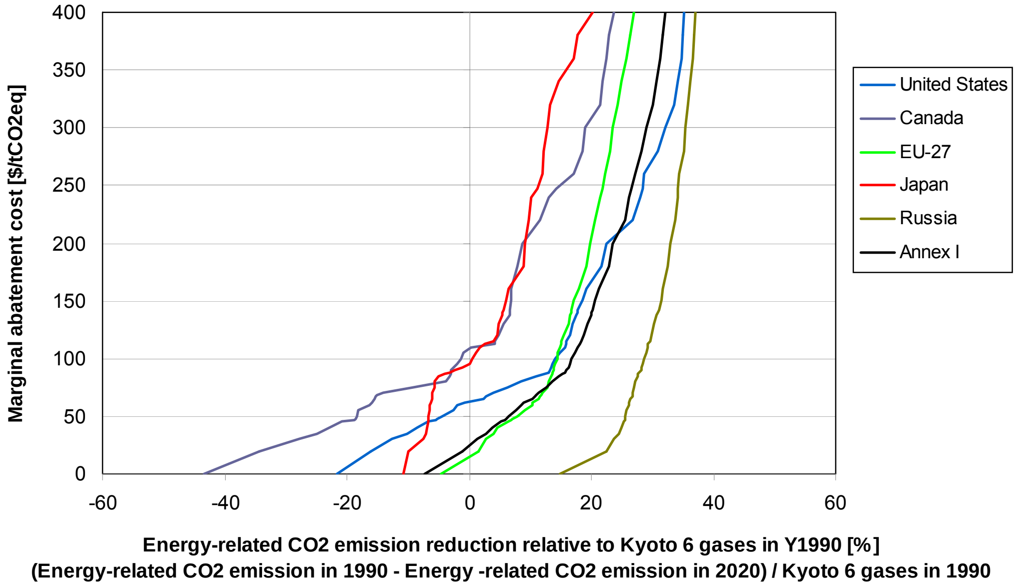


Fig.4-1 Marginal cost curves of Energy-related CO_2 emissions of 2020 (emission reduction relative to 1990's)

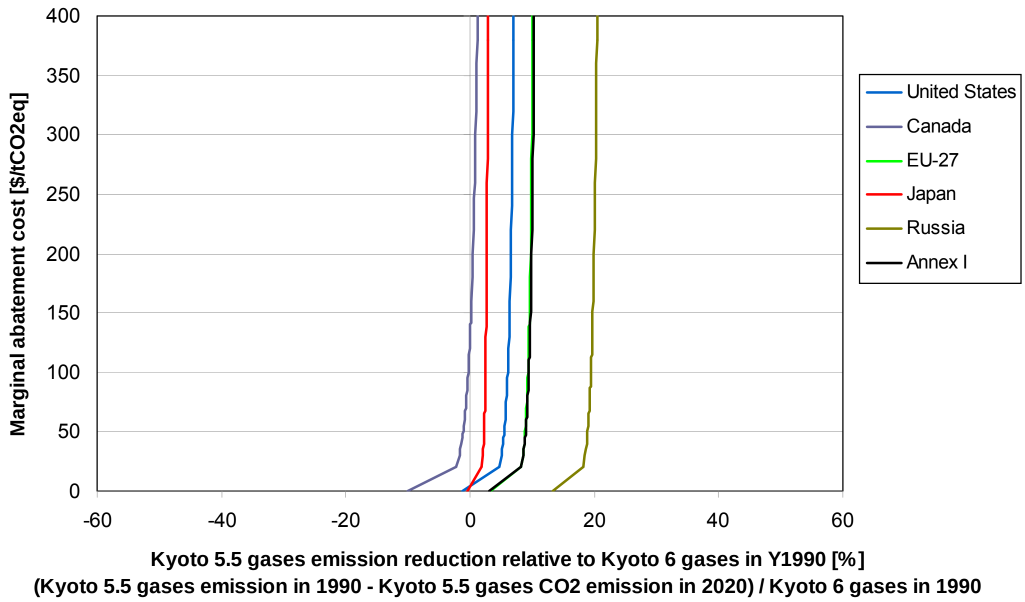


Fig.4-2 Marginal cost curves of Kyoto 5.5 gases (Non-Energy-related CO_2, CH_4, N_2O and F-gases) emissions of 2020 (emission reduction relative to 1990's)

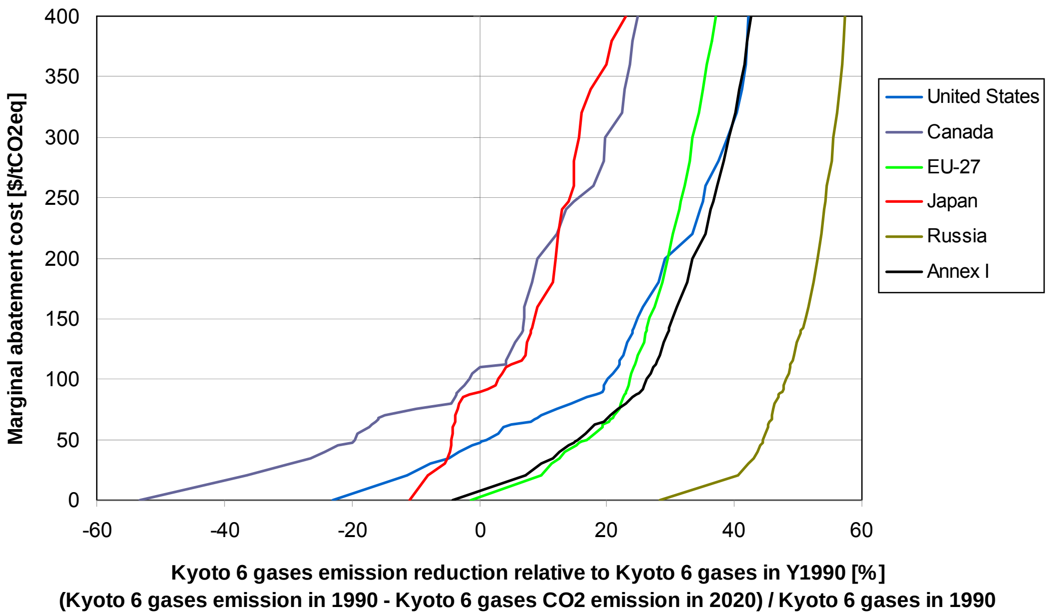


Fig.4-3 Marginal cost curves of GHG (6 gases) emissions of 2020 (emission reduction relative to 1990's)

2. Marginal abatement cost curves in 2020 based on 2005 GHG emissions

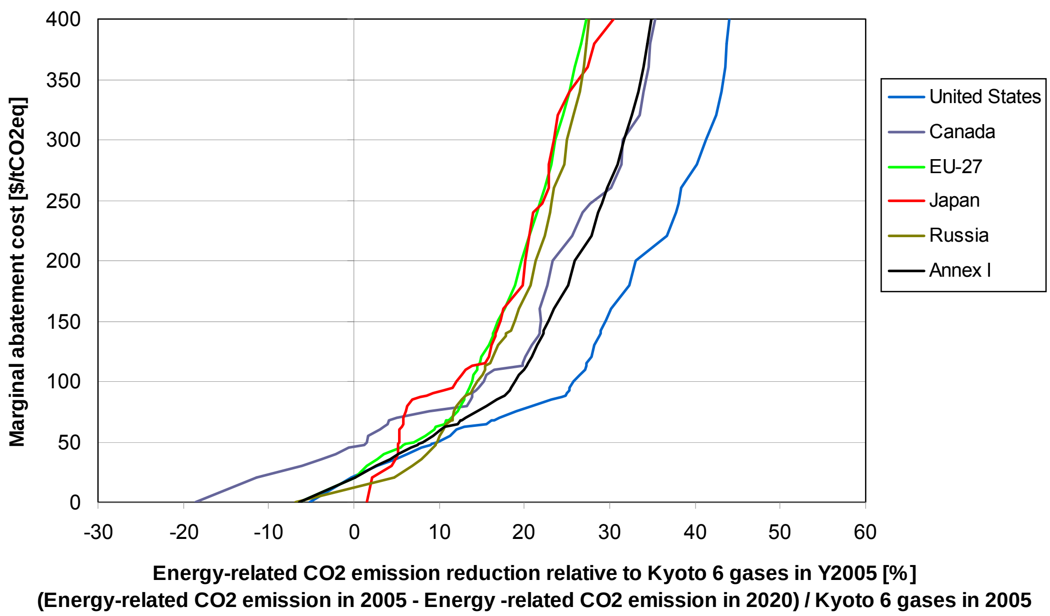


Fig.4-4 Marginal cost curves of Energy-related CO_2 emissions of 2020 (emission reduction relative to 2005's)

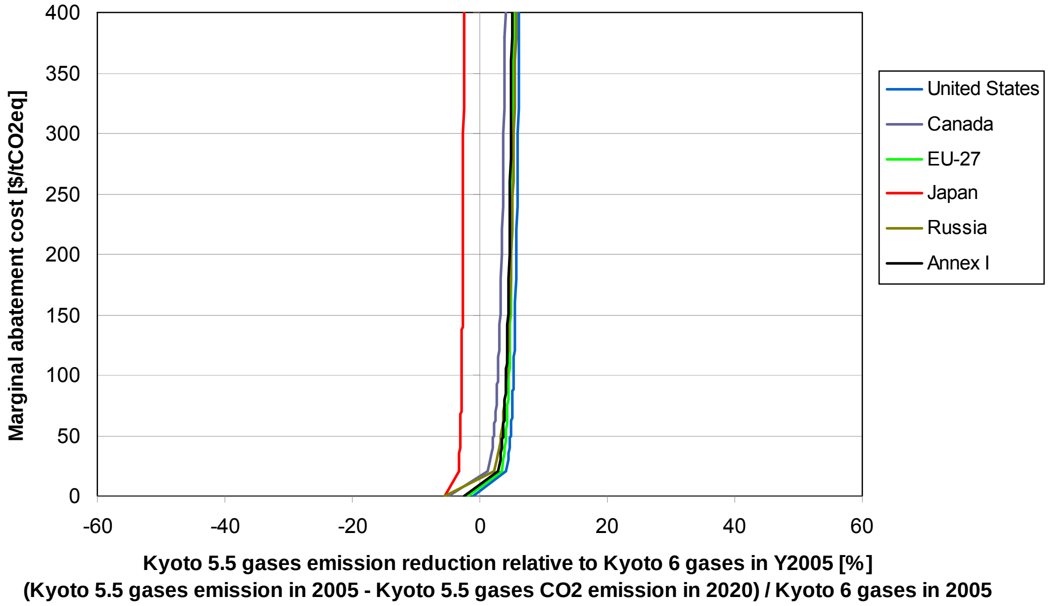


Fig.4-5 Marginal cost curves of Kyoto 5.5 gases (Non-Energy-related CO_2, CH_4, N_2O and F-gases) emissions of 2020 (emission reduction relative to 2005's)

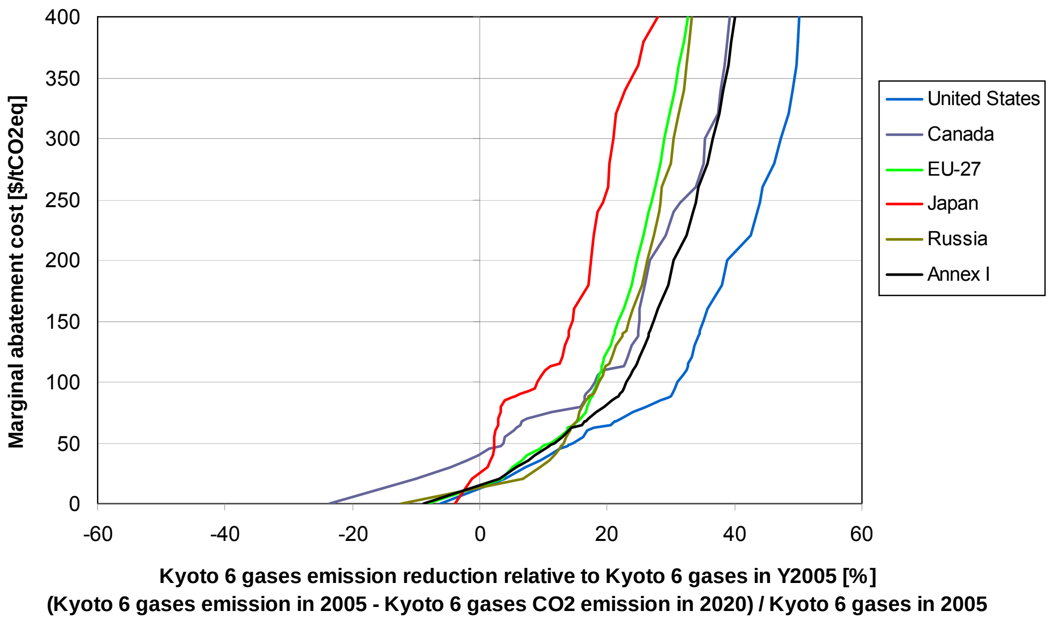


Fig.4-6 Marginal cost curves of GHG (6 gases) emissions of 2020 (emission reduction relative to 2005's)

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