Japan's Energy Outlook for 2050 with Stochastic Sectoral Energy Modelling[1]

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Abstract

The increasing understanding of climate change and energy security issues will put significant constraints on the Japanese energy sector. In order to tackle with these problems, it is significant to develop new measures to mitigate fossil fuel consumption and national green house gas emissions, and to shift our society toward low-carbon economy which is unaffected by soaring price of fossil fuel. For achieving such a goal, it is straightforward that promoting innovative energy and environmental technologies to the energy market play a crucial role. On these backgrounds, long-term stochastic energy projection model is developed on a sectoral basis to comprehensively evaluate the impact of different policies and consumer behavior on the market penetration of low carbon technologies. Modelling scheme is fundamentally an engineering-economic model with technology adoption decisions based on cost and energy performance characteristics of competing technologies where logit-type technology selection model and stock turn over model play a key role. Furthermore, it is possible to evaluate the impact of future stochastic behavior of income growth, demography, and energy prices on energy demand and supply through Monte Carlo simulation. As tentative results, with maximum introduction of low-carbon technology assumed in this paper, it is potentially possible to delineate the picture of reducing CO_2 emissions by more than 40% from the current level of CO_2 emissions by 2050.

1 Background

High oil price trend continues and the level of price remains historically high. Geopolitical risks in major oil producing countries have been increasing and new energy security risks are appearing, such as an oil demand increasing in developing countries like China and India, political volatility in OPEC and non-OPEC countries. Concerning global warming problem, the preparation of a post-Kyoto framework for the Second Commitment Period is another important agenda. Thus, the increasing understanding of climate change and energy security issues will put significant constraints on the Japanese energy sector. In order to tackle with both energy security and global warming issues, it is significant to develop new measures to radically mitigate energy consumption and national green house gas emissions. For achieving such a goal, it is straightforward that the wrestling against the energy and environmental issues can only be solved by promoting effective and innovative low carbon technologies to the energy market. In terms of Japan's future energy and environmental policies on this context, it is important to develop a long-term outlook of Japan's energy supply and demand considering domestic and international changes of economic and social trends, and future

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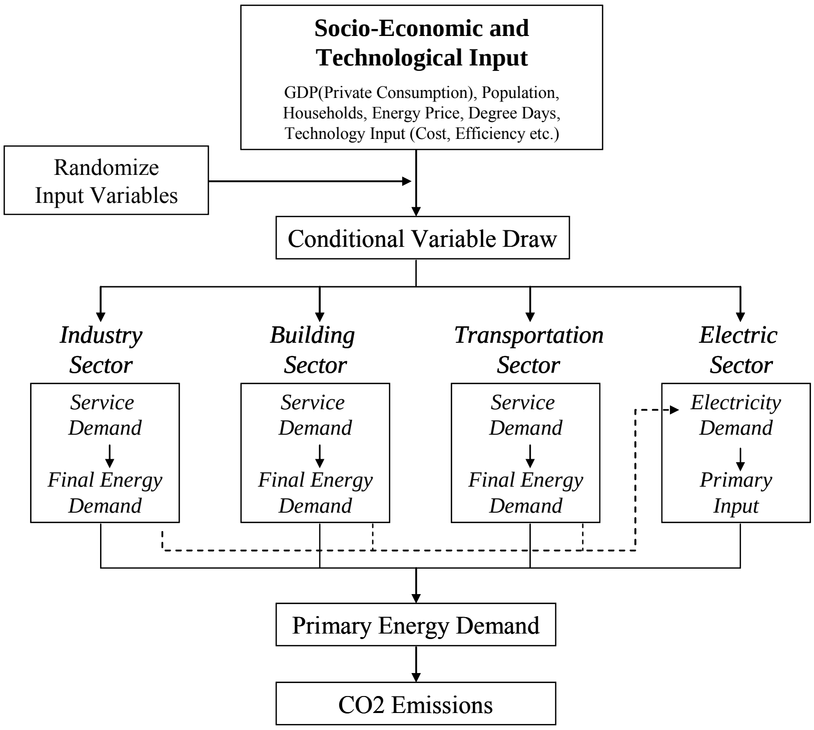
uncertainties associated with economic factors and technology development.

On the above background, this paper elaborates long-term stochastic Japan's energy projection model on a sectoral basis and comprehensive energy scenario to 2050. The concept of the model developed in this paper is different from the existing modeling scheme, such as typical energy modeling method adopting simultaneous econometric equation forecast which is solidly rooted in historic and current conditions (A.Yanagisawa, 2006). The second section describes the main structural characteristics of an integrated economic-engineering model for energy forecast. The third section mathematically formulates the core module of this energy modeling. The fourth section outlines the gist of energy scenario and exogenous assumptions on future economic growth and population adopted for this projection. The fifth section describes the reference results of Japan's energy and environmental projections to 2050, and the sixth section shows alternative scenario "Technology Advancement Scenario". The seventh section focuses on the importance of future uncertainty and stochastic results of energy forecast. Finally, the paper concludes with the key conclusions and implications.

2 Outline of Model Structure

The framework of model is that all energy producing and consuming activities in the economy are modeled using a set of interconnected modules representing the key sectors, where the inputs to one module are the outputs from others. The model is currently composed of Industry Sector module, Building Sector module, Transportation Sector module and Electric Sector module. Industry sector is further disaggregated into iron, cement, paper, chemistry and the other six sub-sectors. Building sector is also divided into residential and commercial sector, and Transportation sector is split into passenger vehicle, freight vehicle and the other 3 transportation sub-sectors. Like NEMS (National Energy Modeling System) developed by US DOE (EIA, 2003), which is adopted to develop long-term national energy forecast, the model exploits energy and capital costs to determine economically optimal technology adoption. Unlike NEMS, it is designed to prioritize simplicity, with the goal of providing a system that produces results quickly out to 2050 (SEDS, 2008). In addition, the model in this paper is structurally different from econometric-type model which forecast is heavily dependent on historical data trend and basically incapable of dealing in a consistent way with the market emergence and consumer adoption of innovative technology which has never penetrated in the past period. Figure 1 roughly illustrates the modelling structure. Numerous indicators such as economic growth, crude oil price, population and degree-days are assumed exogenous variables with statistical distributions that follow specific probability functions. Based on these assumptions, the first step is to calculate energy service demand in each category. Space cooling, space heating, water heating, cooking and plug load in building sector, automobile ownership in transportation sector and iron production, cement production, paper production, ethylene production and index of industrial production in industrial sector are calculated on the basis of the parameter associated with economic activity indicators. Thereafter, fuel demand is determined through end-use energy technology selection based on logit function considering energy cost which is described later. This method allows us to explicitly take into consideration the competition among energy sources. Thus, economic activity indicators, thus, mainly determine the energy service demand while energy cost specifies the configuration of the energy source. Electricity demand in the end-use sectors is aggregated and put as input into electric sector module which determines the optimal power generation mix and calculates the energy input in this sector. Finally, final energy demand and the input into conversion sector such as electric sector is combined together into primary energy demand in a consistent way, following which step anthropogenic CO_2 emissions are eventually calculated.

Figure 2.1: Schematic View of Energy Modeling Framework



Energy service demand in each sector is satisfied by numerous energy consumed facility and appliance which is described in stock turnover model. Fundamentally, the model is organized by a bunch of stock turnover models which serve fuel supply to energy service demand. For example, in building sector, space heating demand is supplied with gas heating, oil heating, electric resistance, air source heat-pump, and ground source heat-pump system. Causality between energy service demand and energy source demand is modeled by stock turnover model where newly added stock is selected through logit function. Based on this modeling, we assume future uncertainty in exogenous variables such as macroeconomic indicators, energy prices and demographic factors through Monte Carlo simulation, which allows us to analyze future uncertainty of energy demand and resulting CO_2 emissions to 2050.

3 Mathematical Description of Model Structure

The model can be regarded as a series of stock turnover models running in parallel that track equipment characteristics and market share as time progresses (Marnay,2008)(SEDS,2008). In energy supply appliance selection, logit function is employed to assign a share of the energy service demand growth to the competing technologies. The logit computes a market share based on the technologies' levelized costs of energy and the other influential factors. Capital costs and fuel costs are used to calculate the levelized cost of energy for each technology. Capital costs can be decreased by R&D and learning. The effects of R&D are treated with uncertainty and can be adjusted to try to capture the level of investment in R&D. The combination of all these factors produces a levelized cost of energy that is dedicated to determine how the market share of new capacity additions will be given to the competing technologies. Once the stock of capacity has been changed to reflect additions and retirements, the expected amount of energy supply, based on installed capacity, that can be produced from each technology is calculated. Hence, this stock turnover model is able to reflect future radical change of energy supply structure, whereas typical energy modeling method adopting simultaneous econometric equation forecast is deeply derived from historic trends and is therefore incapable of incorporating future unprecedented structural change. On the basis of the amount of energy supply from each end-use technology and the corresponding energy intensity, the fuel demand is calculated. This leads to a CO_2 emissions calculation that is determined by the carbon content of each fuel. The mathematical outline of stock turnover model, which plays a central role in our modeling framework, is formulated as follows.

$$EnergyDemand_{se\in S,sv\in T(se)\,fu\in U} = F(EnergyService_{se\in S,sv\in T(se)}, x_{\forall te;te\in V(se,sv)}, y_{\forall te;te\in V(se,sv),\,fu\in U})$$

$$EnergyService_{se\in S,sv\in T(se)} \sim f(EnergyService_{se\in S,sv\in T(se)} \,|\, \alpha_{se\in S,sv\in T(se)})$$

$$x_{te\in V(se,sv)} \sim g(x_{te\in V(se,sv)} \,|\, \beta_{te\in V(se,sv)})$$

se: Element of energy sector, *sv*: Element of energy service, *fu*: Element of fuel, *te*: Element of technology,
S: A set of energy sector, *T*: A set of energy service, *U*: A set of fuel, *V*: A set of technology,
EnergyDemand : Energy source demand, *EnergyService* : Energy service demand
x : Technological parameters such as fixed cost, operational cost, lifetime, energy efficiency etc.
y : Matrix relating technology to fuel type
$f(\,|\,\alpha), g(\,|\,\beta)$: Probability density function (pdf) with scale parameter α and β
F( ) : Function describing energy flow from energy service demand to fuel demand

Following equations are more detailed mathematical formulation of stock turnover.

Newly-added appliance

Newly added appliance or facility is estimated through the difference of energy service demand forecast and total stock of appliance.

$$AddService_{yr,se,sr} = EnergyService_{yr-1,se,sr} - TotStock_{yr-1,se,sr}$$

$$TotStock_{yr,se,sr} = \sum_{tech}\sum_{vin} StockByVintage_{yr,se,sr,tech,vin}$$

$$RetireService_{yr,se,sr} = \sum_{tech} FlowVintage_{yr,se,sr,tech,'VinMax'}$$

$$TotAddition_{yr,se,sr} = Max[0, AddService_{yr,se,sr} + RetireService_{yr,se,sr}]$$

yr : year, *se* : sector, *sr* :energy service carrier, *tech* : technology, *vin* : vintage, *VinMax* : maximum number of vintage, *AddService* : Increase in appliance, *EnergyService* : Energy service demand, *TotStock* : Total appliance stock, *RetireService* : Retired appliance stock, *FlowVintage* : Energy service stock flow to next vintage, *TotAddition* : Total additional energy service, *StockByVintage* : Appliance stock vintage

Logit-based Selection

Market share of newly-added appliance to overall stock is calculated by dividing the utility of each technology by the sum of utility over all technologies. Utility is determined through multiplying the number of attributes, such as the levelized cost of energy for the various appliances, to a scaling factor. The scaling factor determines how sensitive the logit function is to differences in the attributes, for instance, the levelized cost; if the scaling factor equals zero, then equal market share will be given to each technology, whereas, if the scaling factor is much greater than 1, the technologies with the most desirable attributes, such as lowest levelized costs of energy, will gain most of the market share. Utility is a function of certain elements of the vector of attributes and scaling factor α, generally linear in parameters. In this paper, levelized costs of each appliance is only incorporated as an attribute in utility function.

$$TechShare_{yr,se,sr,tech} = \frac{exp(Utility_{yr,se,sr,tech})}{\sum_{tech} exp(Utility_{yr,se,sr,tech})}$$

$$Utility_{yr,se,sr,tech} = \sum_{attr} \alpha_{yr,se,sr,tech,attr} * x_{yr,se,sr,tech,attr}$$

$$TotAddTech_{yr,se,sr,tech} = TotAddition_{yr,se,sr} * TechShare_{yr,se,sr,tech}$$

(if $vin = 1$)

$$AddVintage_{yr,se,sr,tech,vin} = TotAddTech_{yr,se,sr,tech}$$

(if $vin = 2$ to $VinMax$)

$$AddVintage_{yr,se,sr,tech,vin} = FlowVintage_{yr,se,sr,tech,vin-1}$$

α: scaling parameter for the logit function, *TotAddition* : Total additional energy service, *Utility* : Total utility for each technology, *TechShare* : Share of each technology, *TotAddTech* : Additional energy service technology, *AddVintage* : Newly added energy service technology

Appliance Stock Balance

This formulation describes appliance stock balance.

$$StockByVintage_{yr,se,sr,tech,vin}$$
$$= StockByVintage_{yr-1,se,sr,tech,vin} + AddVintage_{yr-1,se,sr,tech,vin} - FlowVintage_{yr-1,se,sr,tech,vin}$$

Spending Time in Vintage

Following equation explains lifetime of each vintage.

$$TimeInVintage_{yr,se,sr,tech} = \frac{LifeTime_{yr,se,sr,tech}}{NumOfVintage_{se,sr,tech}}$$

Flow to next vintage is described as follows.

$$FlowVintage_{yr,se,sr,tech,vin} = \frac{StockByVintage_{yr,se,sr,tech,vin}}{TimeInVintage_{yr,se,sr,tech,vin}}$$

TimeInVintage : Amount of time the technology spends in each vintage [years], *LifeTime* : Maximum survival year of technology [years], *NumOfVintag* : Number of vintage of technology

Energy Requirement

This formulation describes recursive equation of energy requirement (energy input to appliances) balance.

$$ReqmByVintage_{yr,se,sr,tech,vin}$$
$$= ReqmByVintage_{yr-1,se,sr,tech,vin} + ReqmAddVintage_{yr-1,se,sr,tech,vin} - ReqmFlowVintage_{yr-1,se,sr,tech,vin}$$

ReqmByVintage : Energy requirement by vintage, *ReqmFlowVintage*: Energy requirement flow to next vintage, *ReqmAddVintage*: Newly added energy requirement

(if $vin = 1$)

$$ReqmAddVintage_{yr,se,sr,tech,vin} = ReqmIntsty_{yr,se,sr,tech} * TotAddTech_{yr,se,sr,tech}$$

(if $vin = 2$ to $VinMax$)

$$ReqmAddVintage_{yr,se,sr,tech,vin} = ReqmFlowVintage_{yr,se,sr,tech,vin-1}$$

ReqmIntsty: Energy requirement intensity

Energy Requirement Intensity

$$AvgReqmIntsty_{yr,se,sr,tech,vin} = \frac{ReqmByVintage_{yr,se,sr,tech,vin}}{StockByVintage_{yr,se,sr,tech,vin}}$$

AvgReqmIntsty: Average energy requirement intensity

Energy Demand

$$ReqmFlowVintage_{yr,se,sr,tech,vin} = AvgReqmIntsty_{yr,se,sr,tech,vin} * FlowVintage_{yr,se,sr,tech,vin}$$

$$ReqmByVinByEne_{yr,se,sr,tech,ene,vin} = ReqmByVintage_{yr,se,sr,tech,vin} * Energy_{tech,ene}$$

$$EnergyDemand_{yr,se,ene} = \sum_{sr}\sum_{tech}\sum_{vin} ReqmByVinByEne_{yr,se,sr,tech,ene,vin}$$

ene: energy source

Energy: Energy carrier which technology consumes, *ReqmByVinByEne* : Energy requirement by vintage by energy source, *EnergyDeman* : Energy demand

4 Energy Scenario and Major Assumption

4.1 Energy Scenario

The energy supply and demand structure changes greatly with various factors such as economic trends and the advancement of technological developments. Within a very long time frame, such as the period up to 2050, significant changes are likely to arise. Therefore, it is important to analyze several scenarios assuming different sets of economic and technological conditions. In this analysis, we assume “Reference Scenario” and “Technology Advancement Scenario”. The latter scenario assumes a higher level of technology development and adoption in energy market to 2050.

Reference Scenario

The reference scenario represents the most probable state of future energy supply and demand using various assumptions based on highly likely economic trends, current technology developments and energy policies. This scenario mainly serves as the basis of comparison with the Technology Advancement Scenario assuming progressive technology development.

Technology Advancement Scenario

Innovative energy technology enables significant improvements in energy efficiency, and thus can potentially make large contributions to energy security and global environmental protection through increased energy self-sufficiency and decreased CO_2 emissions. It is, however, quite uncertain to make accurate predictions concerning the magnitude of technology development in the future in terms of the timing of technology development, progress, and practical application, and also in terms of how rapidly consumer adoption is encouraged and new technologies will penetrate the market. Therefore, in the technology advancement scenario, we made assumptions concerning various energy-saving technologies and innovative low-carbon technologies currently under development or in the initial stage or threshold of implementation. The market penetration is assumed to be more extensive than in the reference scenario, due to breakthroughs in technology development, etc. In this scenario, the prospect of economic growth, population and energy price is identical to reference scenario.

4.2 Major Assumption

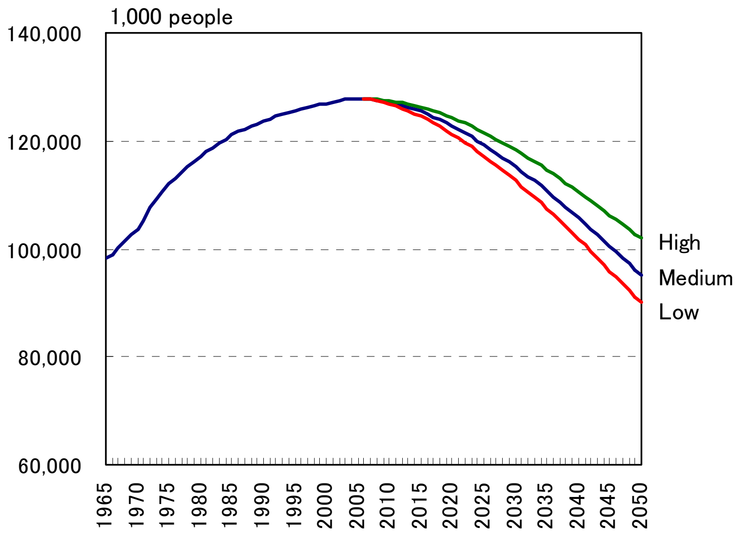
Prospects for Energy Technology

The underlying prospect about future energy technology and its specification is based on long-term perspective about energy technology developed by Ministry of Economy, Trade and Industry (METI, 2005) (METI, 2008a) (METI, 2008b).

Prospects for Economic and Social Structure

Japan's population, an important factor in predicting future economic and social structure, peaked in 2004 and is starting to decline already. A decreasing in population would result in decreased demand for goods and services if expenditure per capita remains the same, and also result in a decreased supply of goods and services if labor productivity remains the same. However, if labor productivity increases due to technology development, thus leading to growth of income per capita, the expenditure per capita may also increase. Thus, even with the decreasing population society, economic growth can be maintained through an increase in labor productivity and in income and expenditure per capita. In this analysis, we assume, for the period up to 2050, that the Japanese economy will show moderate growth with an average real GDP growth of around 1.3% per annum, in spite of a decreasing population. The real GDP growth per annum is expected to be 1.7% for the period up to 2030; however, in subsequent years, the growth rate will gradually slow down in accordance with population decrease and other factors. Nevertheless, the GDP per capita is expected to continue steady growth at a rate of 2.0% to 2050.

Figure 4.1: Prospects for the Japanese Population



(Source) Derived based on mid-level estimates from the "Prediction of Japan's Future Population" produced in December 2006 by National Institute of Population and Social Security Research.

Prospects for Energy Price

The price of crude oil has been shifting within a historically high range due to the following factors: an increase in oil import by rapidly growing major Asian countries such as China and India; unstable political situation in the Middle East. These factors that result in tight and unbalanced oil supply and demand were combined with the influx of speculative money into the oil futures market, producing a record-breaking oil price. We assume that the present high price, uncorrelated with the actual demand, will gradually be corrected by the following factors: more favorable conditions for upstream development produced by a higher oil price; increased output from non-OPEC countries; and withdrawal of speculative money triggered by tight-money policies in developed countries. In the mid- to long-term, oil price is expected to rise gradually as developing nations, particularly in Asia, increase their demand for oil as they grow economically, while the following factor will contribute to gradual rise of crude oil prices: slower production speed in non-OPEC countries; and stagnation or loss of efficiency in upstream development due to the emergence of energy resource nationalism particularly in OPEC countries. On this background, the price of oil is assumed to drop temporarily from the present level due to increased production in non-OPEC countries. However, it is assumed that the supply will again be tight in the international oil market after 2010, followed by a moderate rise in price, reaching $54 (nominal price of $89) per barrel in 2030 and reaching $68 (nominal price of $166) per barrel in 2050. The basic price trend and the background explanation is based on US DOE (EIA,2008a).

Prospects for Major Activity Indexes

The following subsections describe the future trend of activity indexes, which are important when predicting future energy demand.

Table 4.1: Prospects for Major Activity Index

	Actual				Forecast			Average annual growth rate (%)			
	1980	1990	2000	2005	2010	2030	2050	1990/ 1980	2005/ 1990	2030/ 2005	2050/ 2005
Real GDP (Unit: trillion yen, value as in 2000)	303.8	448.7	504.3	547.0	606.6	825.0	986.9	4.0	1.3	1.7	1.3
GDP per capita (Unit: million yen)	2.60	3.63	3.97	4.28	4.77	7.16	10.37	3.4	1.1	2.1	2.0
Total population (Unit: million)	117.06	123.61	126.93	127.77	127.18	115.22	95.15	0.5	0.2	-0.4	-0.7
Crude steel production (Unit: million tons)	107.39	111.71	106.90	112.72	113.70	115.80	118.43	0.4	0.1	0.1	0.1
Ethylene production (Unit: million tons)	3.87	5.97	7.57	7.55	7.14	6.90	6.74	4.4	1.6	-0.4	-0.3
Cement production (Unit: million tons)	85.88	86.85	82.37	73.93	68.66	65.80	64.63	0.1	-1.1	-0.5	-0.3
Paper/paperboard production (Unit: million tons)	17.53	28.54	31.74	31.05	32.61	36.39	36.92	5.0	0.6	0.6	0.4
Commercial floor space (Unit: million m2)	936	1,285	1,656	1,758	1,904	2,173	2,003	3.2	2.1	0.9	0.3
Passenger vehicle (Unit: million)	23.65	35.15	1,419.7	57.05	60.29	63.48	61.67	4.0	3.3	0.4	0.2
Freight vehicle (Unit: million)	14.0	22.3	578.0	17.8	16.5	14.4	12.5	4.7	-1.5	-0.8	-0.8

(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

- Production of raw material products

The energy demand from the industrial sector is closely related to production activities. Since energy consumption structures differ among industries, we have to predict production trends for different types of industries. Above all, the trend of energy-intensive raw material production (crude steels, cement, ethylene and paper/paperboard) is particularly important. The volume of raw material production is expected to show a general decreasing trend as civil engineering and construction demands will become stagnated due to saturation of social capital infrastructures, residential housing and office buildings, resulting from the decreasing population. For example, based on the expected increase in the demand for high-grade steel materials (e.g. steel sheets for automobile production), crude steel production volume in the range of 110–120 million tons will be sustained in 2050.

- Floor space for commercial sector

While the indexes for business activities include commercial sales volume index, it is apparent from past statistical validation that energy demand in the commercial sector is highly correlated with the amount of floor space. With the shift to a service-oriented economy, floor space for commercial sector has increased steadily to 2050. Even though the amount of floor space is expected to keep expanding, the growth rate will slow down due to population decreases.

- *Transport demands*

Activity indexes crucial for energy demand forecast in the transportation sector include passenger transport demand and freight transport demand in terms of automobile ownership. Currently in Japan, the sluggish economy and peaking population growth have contributed to the recent leveling off of passenger transport. For a while, passenger transport will show a slight increase due to economic recovery; however, after reaching a peak around 2020, the growth will turn negative due to population decrease. Freight transport demand, which is closely related to production activities, will remain flat or decrease, because the expected increase of production activities will be offset by downsizing of manufacturing industries and the shift to a service-oriented economy.

Nuclear power generation

Concerning nuclear power generation, against increasing demand for electricity, we assume that nine new nuclear power plants will be built up(METI, 2008b).

Table 4.2: Prospects for Nuclear Power Generation

GW	1990	2005	2010	2020	2030	2040	2050
Nuclear	31.48	49.58	50.14	61.50	61.50	61.50	61.50

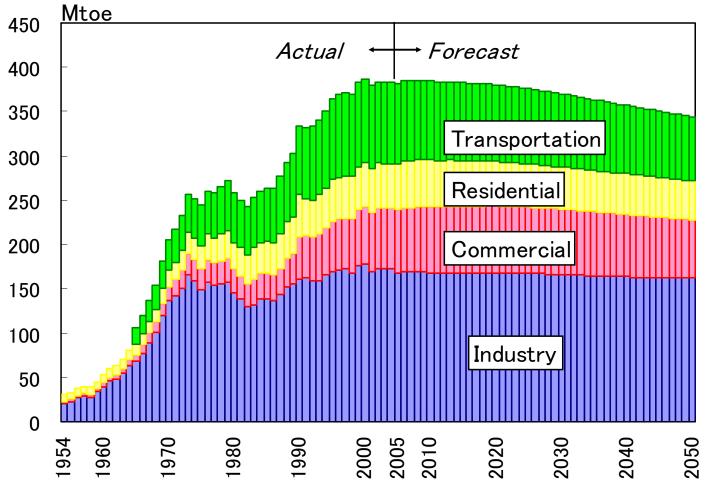
Regarding existing nuclear power plants, adequate measures against plant aging will enable their extended operation over a period of about 60 years, and therefore, we do not assume the decommissioning or phase-out to 2050. And we assume that the operating factor will be around 80% in future, while it is presently at a low level due to the shutdown of some nuclear power plants.

5 Projection Results in Reference Scenario

Final Energy Demand

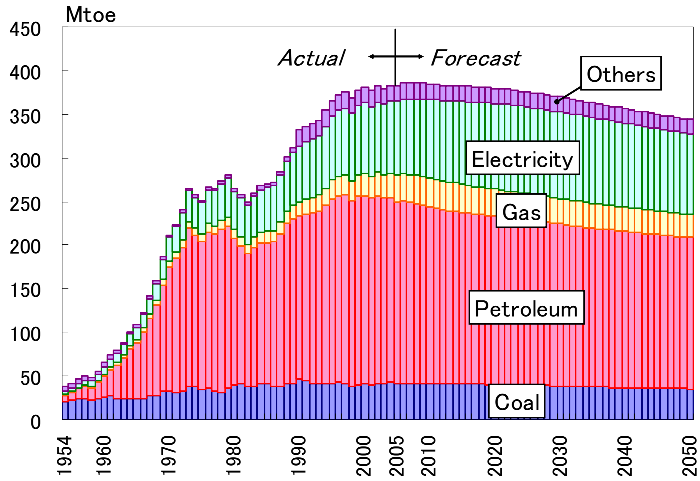
After World War II, Japan set about reconstructing its economy. During the almost two decades of high economic growth between the 1950s and the 1970s, the nation’s energy consumption steadily increased. The two oil crises of the 1970s were serious shocks to the Japanese economy, and brought the period of high economic growth to an end. The nation’s industries thereafter implemented serious energy conservation measures. Eventually, development of energy conserving appliances significantly advanced and promptly penetrated into the market. The result was the continuation of economic growth without an accompanying increase in energy demand. Final energy consumption, however, has been growing constantly since the mid 1980s, when energy-saving measures introduced after the Oil Crisis had been saturated. In subsequent years, final energy consumption continued growing due to increased automobile ownership and so on. From around the end of the 1990s, however, the growth of final energy demand began slowing down due to the materialization of newly introduced energy-saving measures supported by governmental institutional schemes called “Top runner standard” and a shift to a service-oriented industrial structure.

Figure 5.1: Final Energy Demand by Sector (Reference Scenario)



(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

Figure 5.2: Final Energy Demand by Energy Source (Reference Scenario)



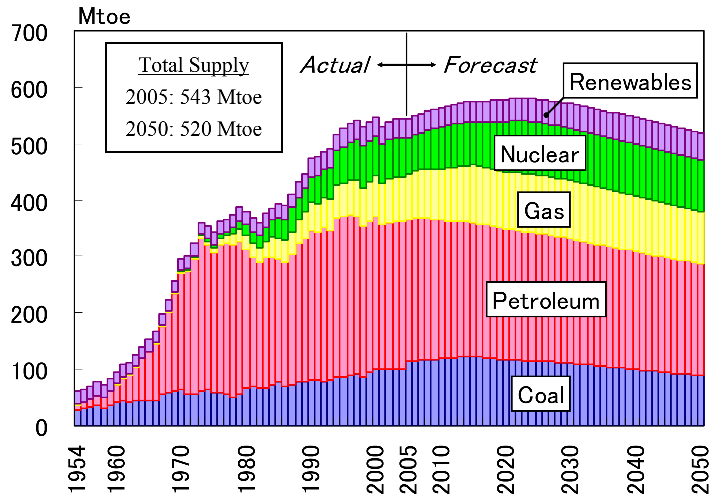
(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

According to the forecast, final energy demand will show gradual decreasing trend by 2050 due to smaller population and effects of various energy conservation efforts. By energy source, electricity demand is projected to continuously grow to 2050. With the improved efficiency of air conditioners, electric water heaters attracting more consumers, there will be a shift in energy demand to electricity; electricity will acquire a share of nearly 30% by 2050 from 22% in 2005. Concerning petroleum products and gas, large increases are unlikely because utilization of these fuels will decrease with the improved efficiency of appliances, and also because a shift to electricity is expected in each field of application. Particularly, automobile sector will achieve significant energy-saving and improve fuel efficiency of conventional vehicles. Hybrid vehicles, which are already commercially viable in the market, do not have infrastructure-imposed restrictions, and the disparity between their price and that of conventional vehicles is getting smaller. Therefore, hybrid vehicles are expected to penetrate the market more deeply and contribute to mitigate oil demand even in the reference scenario.

Energy Supply

In 1973, oil supplied 77% of nation's energy requirements. When the first oil crisis occurred in 1973, crude oil prices soared and supply was threatened with interruptions. To stabilize its energy supply, Japan endeavored to reduce its dependence on oil through the introduction of nuclear power and natural gas. Crude oil prices once again increased dramatically during the second oil crisis in 1979, accelerating the process of introducing nuclear power and natural gas, and propelling the development of alternative energy. Japan's present level of oil dependence is high at 50%, but that represents a significant improvement over the 77% level at the time of the first oil crisis. The use of nuclear power and natural gas has increased to provide alternative to oil, with the former supplying 9% and the latter supplying 14% of the total. Thus, Japan continues to diversify its energy mix. In the 1980s, reflecting on the decreasing trend of energy prices and the stagnation of energy conservation, Japan's primary energy supply began to grow again. From around the end of the 1990s, however, the increase of Japan's primary energy supply started to slow down, based on the promotion of energy conservation measures supported by energy efficiency standards and the shift to less energy intensive economic structure more oriented to service sector.

Figure 5.3: Primary Energy Supply (Reference Scenario)



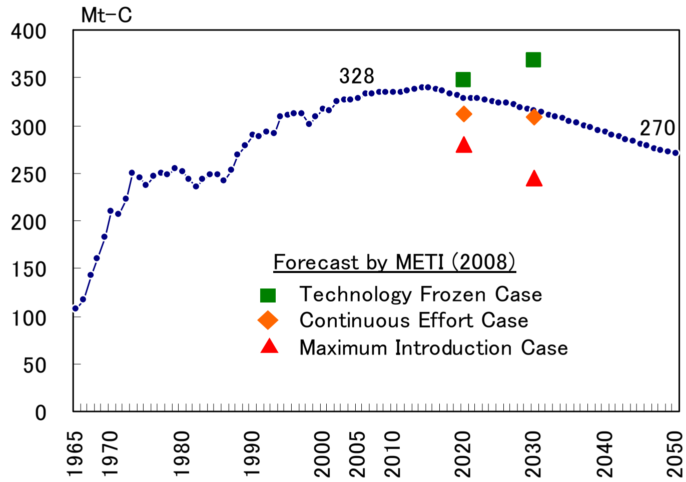
(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

In the reference scenario, Japan's primary energy supply will level out until around 2020, and thereafter represent a slight decreasing trend. Concerning fossil fuels, oil demand is expected to decrease because highly energy-efficient measures will be deployed more extensively in the transport sector and the proportion of oil in final energy consumption will decrease. The dependency of oil will be below 40% after 2020. Coal demand will basically flatten out and slowly decline because improved generation efficiency of coal-fired power generation and decreasing coke demand to produce steel products will reduce the amount of coal demand for these purposes. Concerning natural gas, improved efficiency of LNG-fired power generation will level off LNG consumption. Renewable energy, such as photovoltaic and wind power, is the only energy for which consumption is expected to steadily grow for 2050.

CO_2 Emissions

CO_2 emissions from fuel combustion have continuously increased with the growth of fossil fuel demand. Total CO_2 emission in 2005 amounts to 328 million carbon-equivalent tons (13% increase over the 1990 level). In the reference scenario, CO_2 emission is projected to increase to 334 million tons (15% increase over the 1990 level) by 2010, after which a decreasing trend will continue. CO_2 emissions will be below 1990 level after 2030 and decline to 270 million tons by 2050 (7% decrease over the 1990 level).

Figure 5.4: CO_2 Emissions (Reference Scenario)



(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

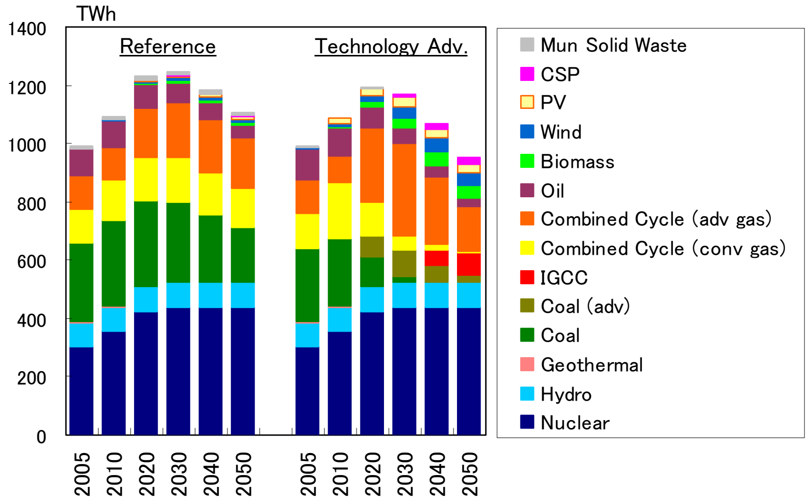
6 Technology Advancement Scenario

6.1 Views on Technology

Electric Power Generation Mix

Concerning nuclear power generation, we assumed the construction of 9 new reactors and smooth growth of the installed capacity by 2050. In reference scenario, given these assumptions, nuclear power generation in 2050 will be a major source of electricity supply with a share of almost 40%. In technology advancement scenario where energy conservation measures massively decrease electricity consumption, the share of nuclear in power generation mix will be enhanced up to nearly half in 2050. Concerning thermal power generation, we expect increased output, but the share, in reference case, will gradually decrease to about 50% by 2050 from current level of 60%, as nuclear power generation increases. In technology advancement scenario, its share will decrease to around 30% by 2050 and significant CO_2 mitigation is expected in power generation sector. Particularly in technology advancement scenario, coal-fired and LNG-fired power generation plants will continue to be used in future to serve various loads from base load to peak load, with integrated gasification combined cycle (IGCC), advanced combined cycle generation and more advanced combined cycle generation with carbon sequestration. Regarding renewable energy including hydropower and geothermal, its share will achieve only about 12% by 2050 in reference scenario from 9% in 2005. By contrast, in technology advancement scenario, its share is expected to grow up to more than 20% by 2050 and renewable is expected to play crucial role to mitigate CO_2 emissions.

Figure 6.1: Power Generation Mix



High-efficiency Lighting, High-efficiency Water Heating System

Lighting energy demand holds large share of total energy consumption in building sector. In Japan's residential sector, energy consumption by lighting has the share of approximately 15% in residential electricity demand, and in typical office building, it covers nearly 20% in total energy demand of office building. Therefore, energy conservation of lighting and acceleration of advances in solid-state lighting (SSL) is important. Among SSL, light-emitting diodes (LEDs) effectively convert electric power into light, reducing losses from converting electric power into heat. The best white LEDs available today can produce about 50 lpw (lumens per watt). By contrast, incandescent lamps typically produce around 15 lpw. Therefore, LED lamps may appear less energy intensive, but they are still more expensive and have very low light output. If ongoing development efforts for its general lighting applications are successfully making progress, LEDs are expected to contribute to mitigate lighting energy demand. In technology advancement scenario, about 50% of lighting demand is assumed to be satisfied with LED.

Water heating demand accounts for about 30% of total energy consumed in Japan's residential sector. It is possible to reduce energy demand for water heating by using some energy-efficient water heating appliances. In order to realize energy-efficient hot water supply, electric water heating system potentially contributes to mitigate the fuel consumption. Currently, this technology can be two to three times more energy efficient than conventional water heaters such as electric resistance, gas and oil-fuelled water heaters. By 2050, successive technology developments of heat-pump water system will result in an even higher efficiency and its COP is assumed to accomplish nearly 6.0 in technology advancement scenario. In that case, its share of total ownership of water heater in residential sector will achieve larger share of 60% by 2050 than 30% in reference scenario.

Figure 6.2: Lighting Technology in Building Sector

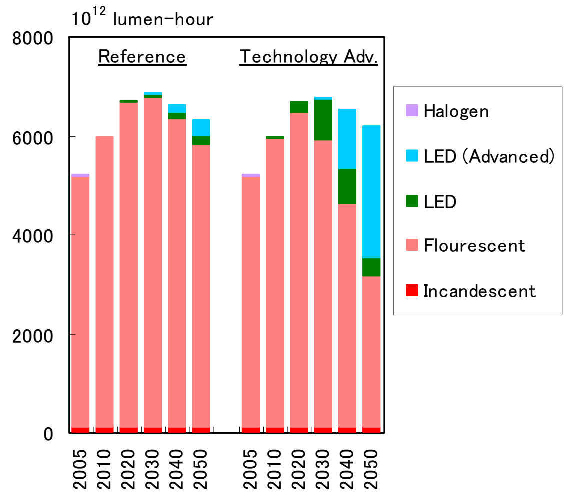
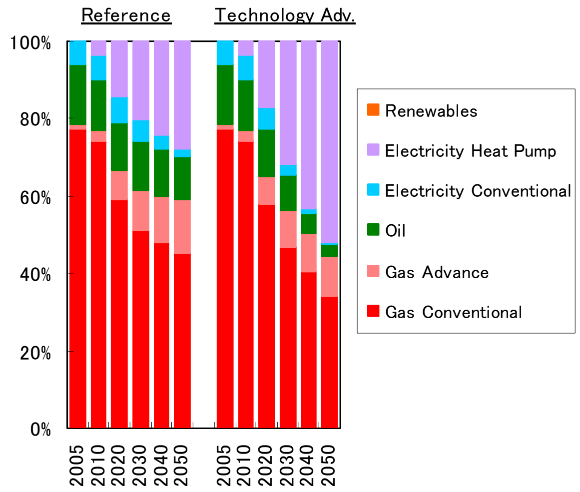


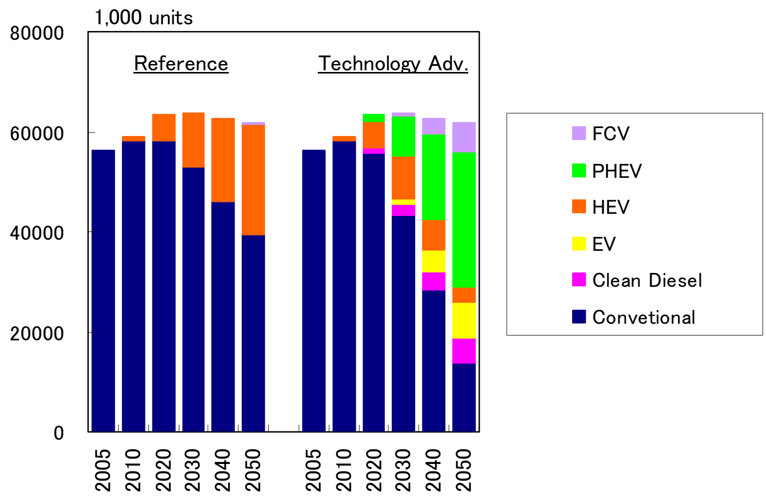
Figure 6.3: The Share of Water Heating System in Residential Sector



Clean Energy Vehicles

Major energy conservational measures in automobile sector is to enhance the fuel economy of conventional vehicles as well as promoting alternative fuels (fuel cell vehicles, natural gas vehicle etc). Concerning electric vehicles and fuel cell vehicles, as these are much more expensive than conventional vehicles and moreover they require the development of supporting infrastructures, their deployments are limited in reference scenario. On the other hand, hybrid vehicles are already commercially available in the market, and the difference between their price and that of a conventional vehicle is getting smaller. Therefore, hybrid vehicles are expected to further penetrate the market with the number exceeding 20 million by 2050 in reference scenario. In technology advancement scenario, on the other hand, supported by the development of peripheral infrastructure dedicated to PHEV, EV and FCV, these CEVs are expected to hold approximately 80% over Japan's passenger vehicle ownership by 2050.

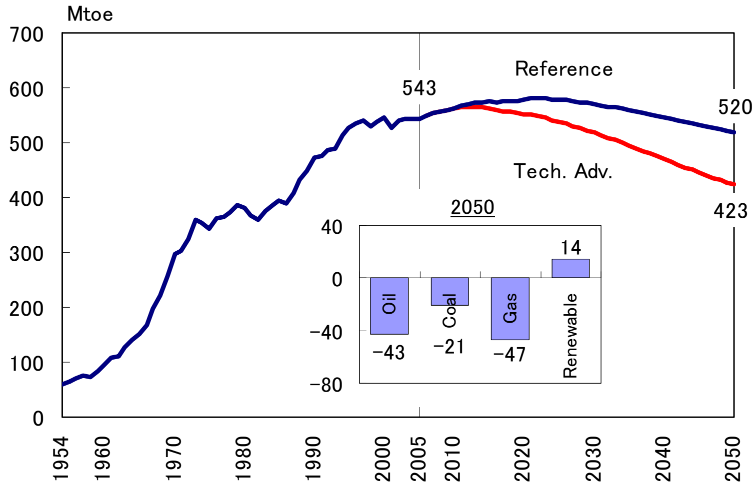
Figure 6.4: Passenger Vehicle



6.2 Technology Advancement Scenario

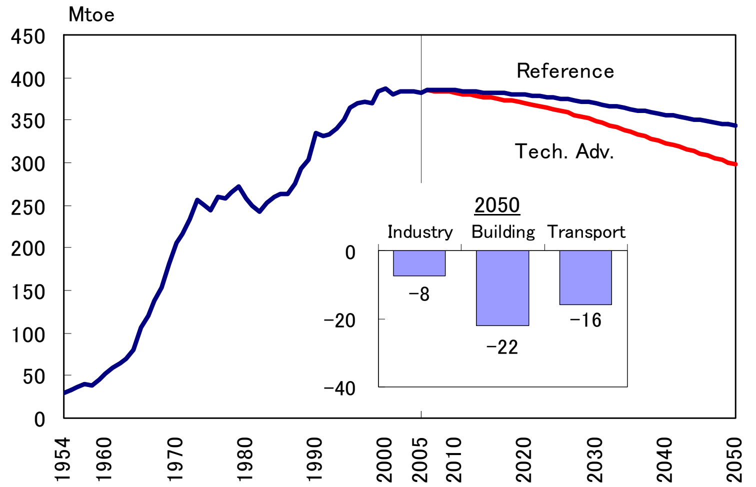
Primary energy supply will show sluggish growth toward 2050, due to various energy conservation measures in both end-use and energy conversion sector. In technology advancement scenario, the amount of energy conservation achieved in 2050 will be 96 Mtoe more than the amount estimated in reference scenario. Concerning primary energy demand by different energy sources, oil demand will decrease by 43 Mtoe with major contributions from higher fuel efficiency in the transport sector. Gas and coal demand mitigation are derived mainly from the deployment of power generation with high conversion efficiency. The decreasing amount of primary energy supply will be larger than the 45 Mtoe reduction in final energy demand because of the additional contributions from decreased fuel demand by energy transformation sector particularly in power generation sector.

Figure 6.5: Primary Energy Supply



(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

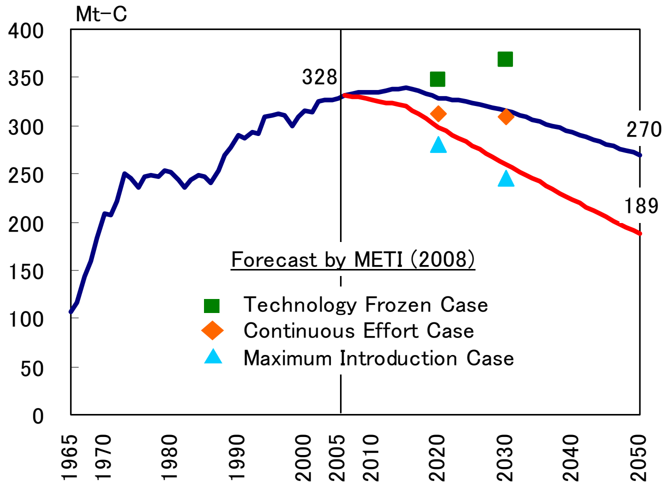
Figure 6.6: Final Energy Demand



(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

Comparing final energy consumption by sector, the building sector will achieve the largest amount of energy-saving (22 Mtoe) accomplished by the spread-out of highly energy efficient appliances. Transport sector will show the second largest amount of energy conservation (16 Mtoe) due to high penetration of clean energy vehicles. By decreasing fuel combustion and increase use of renewable energy, CO_2 emissions in technology advancement scenario will be diminished by 81 million carbon-equivalent tons by 2050. This scenario reveals that, with maximum introduction of low-carbon technology assumed in this paper, it is potentially possible to delineate the picture of reducing CO_2 by more than 40% from the current level of CO_2 emissions up to 2050.

Figure 6.7: CO_2 emissions

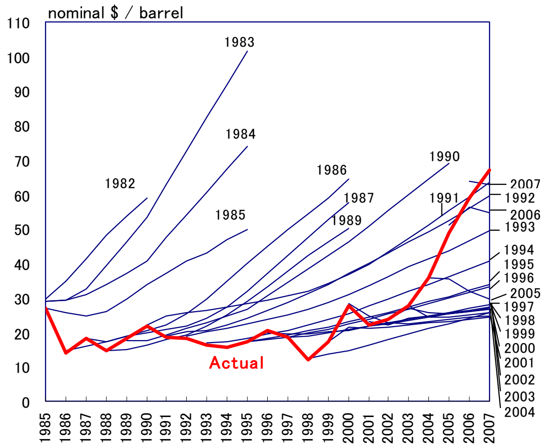


(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

7 Uncertainty Analysis

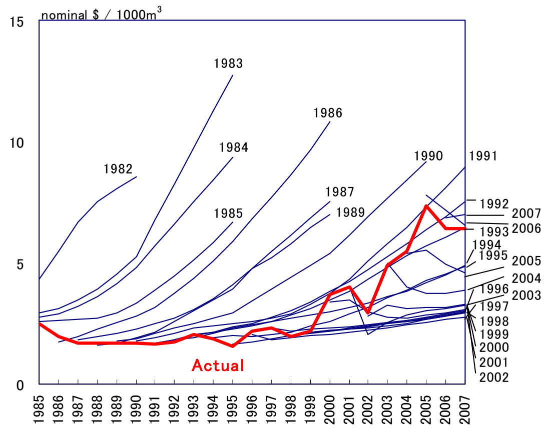
Figure 7.1, 7.2 and 7.3 represent the AEO (Annual Energy Outlook) forecasts of world oil price, wellhead gas prices and U.S. primary energy demand developed by EIA/DOE. Actual trajectory of prices and the years when the prediction was developed are shown. In particular, energy price forecasts change dramatically depending on the year when forecast were created, and there are no forecast to precisely predict the historical trend, implicating that it is critical agenda to taka into consideration the generic uncertainty of long-term forecast (Morgan, 1990).

Figure 7.1: Energy Price Forecast in Annual Energy Outlook (AEO) by DOE (World Oil Price)



(Source) EIA/DOE, Annual Energy Outlook

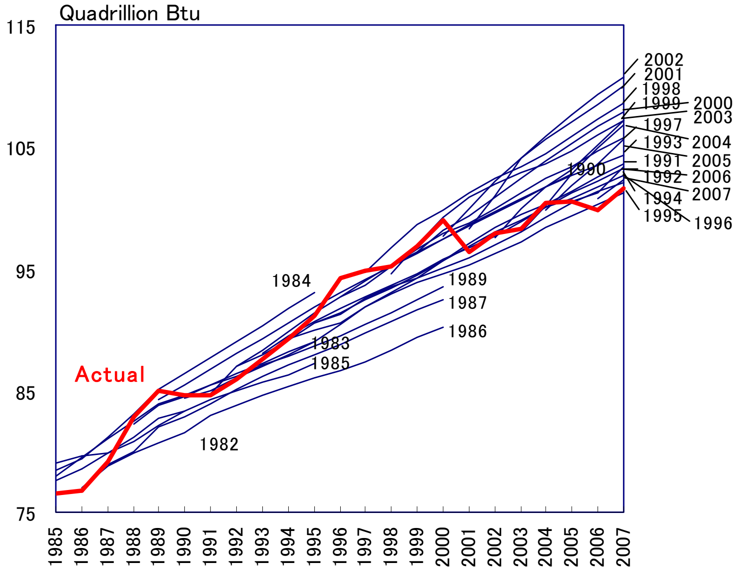
Figure 7.2: Energy Price Forecast in Annual Energy Outlook (AEO) by DOE (Natural Gas Wellhead Prices)



(Source) EIA/DOE, Annual Energy Outlook

In case of world oil price, the prospect developed between 1982 and 1992 represents bullish outlook for the future. The outlook between 1993 and 2004, however, the forecast became bearish under the background of the continuous lower level of oil price at that time period. And then, the bullish prediction has been pervasive again since 2005. Although actual primary energy demand of USA almost outstripped the AEO forecast developed in 1980's, the level of demand has become lower than the AEO developed in 1990's and 2000's.

Figure 7.3: Energy Price Forecast in Annual Energy Outlook (AEO) by DOE (Primary Energy Demand of USA)



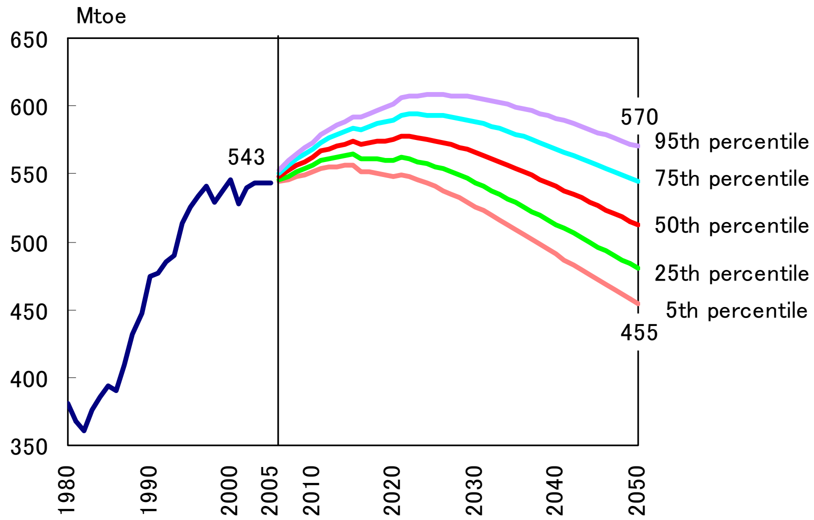
(Source) EIA/DOE, Annual Energy Outlook

In our analysis, we assume future uncertainty in the macroeconomic indicators such as GDP growth, energy price and demographics. In order to take into account this uncertainty, uniform probability distributions for these factors are adopted, which assumes a uniform probability between the maximum and minimum achievable values of each exogenous parameter. The maximum achievable value in 2050 is supposed to be 15% larger than the reference value, and the minimum achievable value is 15% less than the reference value. If the value of certain parameter in 2050 is 1.00, that parameter is randomly drawn between 0.85 and 1.15 in uniform probability. In addition, the minimum and maximum limit is assumed to respectively expand from 0% in 2005 to 15% in 2050.

The development of forecast is based on Monte Carlo simulation, where value from each distribution of specific assumption is randomly picked up and the forecast is recalculated many times. Each prediction adopts a different combination of values for the GDP, population and energy price. In order to conduct the Monte Carlo simulation, we adopt the Analytica™ platform (Lumina Decision Systems, Inc). Figure 7.4 illustrates primary energy demand to 2050 and Figure 7.5 shows CO_2 emissions with probability bands, both simulated in the assumption of reference scenario. As time progresses for the future, the range of value becomes gradually uncertain, reflecting on the larger uncertainty of exogenous variables. Concerning the primary energy demand, it will potentially exhibit from 455 Mtoe in 5th percentile to 570 Mtoe in 95th percentile, and CO_2 emissions, from 218 Mt-C in 5th

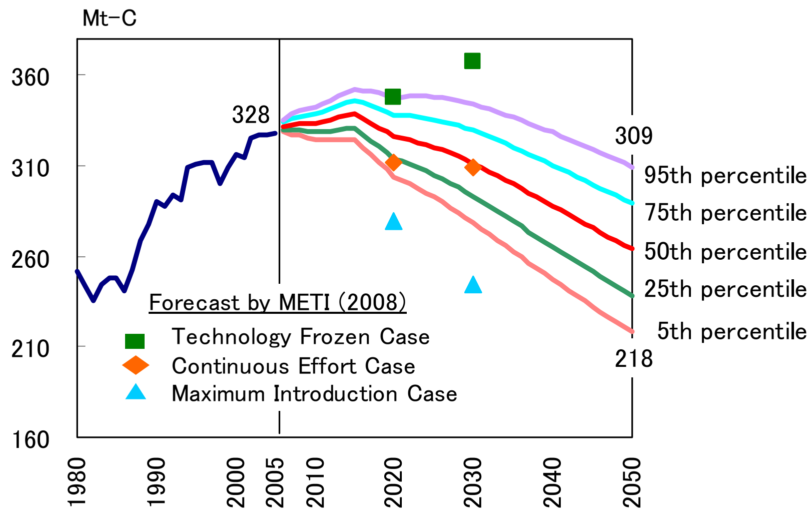
percentile to 309 Mt-C in 95th percentile. These results reveal that, considering the future uncertainty, careful energy policy decision making is required to tackle the energy security and global warming problem in an effective manner.

Figure 7.4: Primary Energy Supply (Reference Scenario)



(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

Figure 7.5: CO_2 emissions (Reference Scenario)



(Source) Actual value is cited from the database of EDMC, IEEJ (IEEJ,2007)

8 Conclusions

This paper explores Japan's energy demand and supply outlook to 2050 and develops a stochastic model for analyzing the impact of the future stochastic behavior of income growth, demographic factor on Japan's energy demand growth to 2050. By decreasing fuel combustion and increase use of renewable energy, CO_2 emissions in technology advancement scenario will be diminished by 81 million carbon-equivalent tons by 2050. This scenario implies that, with maximum introduction of low-carbon technology assumed in this paper, it is potentially possible to reduce CO_2 by more than 40% from the current level of CO_2 emissions up to 2050. In addition, Japan's energy demand in 2050 remains uncertain considering the future uncertainty of the economy, demography and energy prices, which suggests that careful energy policy analysis is required to comprehensively tackle the energy security and global warming problems.

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