The Economic Impact of the Introduction of Hydrogen into Japan's Energy System Towards 2050

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Abstract

This study uses the macroeconomic model, the energy supply-demand model, and the technology evaluation model (MARKAL model) to quantitatively assess what impact ambitious carbon dioxide (CO_2) reduction targets will have on future economic activity and energy supply-demand. In addition, the study assesses to what degree the introduction of hydrogen energy would mitigate the impact.

As the authors have made clear in a previous analysis [1], under the ambitious carbon dioxide reduction targets of 65% or more from the 1990 level by 2050, carbon prices in excess of USD1,000/tCO_2 would be required, which is a figure divorced from reality. The impact of this carbon price would be to reduce real disposable income and cause economic activity to diminish by passing on the cost to fossil fuel prices and electricity prices. The higher the reduction targets, the more strikingly adverse the impact, and depending on the situation, there are indications of a loss of approximately forty per cent of economic growth that is achievable by 2050.

In this context, the study shows that the introduction of hydrogen has the potential to mitigate these adverse impacts. The introduction would focus on power generation by direct combustion of hydrogen. The study indicates that this would result in lower carbon price and would soften the aforementioned forty per cent loss of economic growth to about twenty per cent.

The advantage of introducing hydrogen is even more obvious when the reductions cannot be met with other relatively inexpensive countermeasures alone as the targets become stricter. "Carbon-free" hydrogen will play an important role as a future energy carrier because it is not extremely expensive, it is possible to roll it out to scale, and it does not have the same instability as renewable energy. These values are positioned correctly when we take the long-term view to, say, 2050. We need to consider strategies for the future with a calm eye while always focusing on the uncertainties ahead.

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1. Introduction

Interest in climate change issues seems to have waned somewhat with the changes in the global economy and the Great East Japan Earthquake. Nonetheless climate change remains an important issue. In the long term, the world will have to face up to how to control greenhouse gases, in particular, the carbon dioxide (CO_2) that derives from energy. There is no silver bullet to resolve the problem. Hydrogen, which does not emit CO_2 during combustion, has been attracting attention as the ultimate energy carrier for reducing greenhouse gas emissions. So far, the focus has been mainly on how to increase the use of hydrogen in fuel cells (for automotive use or stationary use). However, there is another way of utilizing hydrogen: by using it as a direct fuel for combined cycle power generation (hydrogen-fired power generation). As well as the potential for supplying electricity on a large scale, this can be regarded as a zero emission power source as long as CO_2 is not emitted during hydrogen production.

In this context, this study estimates the potential of Japan's hydrogen introduction by 2050 using the MARKAL (MARket ALlocation) model [1]. Our research shows that unless ambitious targets are set to reduce CO_2 in the long term, the large-scale introduction of hydrogen is expected to be difficult in economic terms in the absence of extremely rapid technological progress. On the other hand, tens of billions of Nm^3/year of hydrogen will be introduced if a target of reducing CO_2 by 65% or more from the 1990 level is assumed and the introduction of carbon capture and storage (CCS) is restricted. On the basis of this result, we conclude that hydrogen could be one of the key options for future energy choices.

In this study, the energy service demands estimated by an econometric model were exogenously fed to the MARKAL model, and the solutions obtained with these inputs were studied. The forecasts suggest that high carbon price would be required to achieve the ambitious target of reducing CO_2 by more than 65% from the 1990 level, which raises concerns about an adverse impact on the economy.

The aim of this study is to quantitatively evaluate what impact ambitious reduction targets may have on future economic activity, and what role hydrogen would play in that case.

2. Methodology and assumptions

2-1 Methodology

(1) Framework of the calculation

For this study, we use a macroeconomic model, an energy demand-supply model and a technology evaluation model (the MARKAL model). By combining the three models and applying iterative calculation according to the sequence outlined below, we systematically analyze the impact of ambitious CO_2 reduction and the use of hydrogen on the economy and energy supply-demand. Section (2) below outlines each model.

Calculation Process

0	Population and economic policy, primary energy prices, power supply configuration (average unit price for power), etc. are set on the basis of previous studies, and the values are input to the macroeconomic model.
1	Forecast some indicators by the macroeconomic model based on the inputs. GDP related indicators, price indices, etc. are calculated as the result.
2	Input the calculated values for the indicators to the energy supply-demand model. Energy service demands are calculated as the result.
3	The energy service demands calculated by the energy supply-demand model are input to the MARKAL model. As a result of the calculation, the marginal abatement cost for CO_2 emissions (carbon price) is obtained, as well as the primary energy supply and power generation mix. The average unit price for electricity is also calculated based on the calculated power generation mix. The carbon price and average unit price for electricity are updated as the inputs to the macro-economic model in step 1.

As indicated in the box above, the sequence from 1 to 3 is repeated and iterative calculation is conducted until carbon price converges on a fixed value. In the second half of this paper, we only indicate the results after convergence and make discussions.

(2) The macroeconomic model

As the outline in Figure 2-1 indicates, the real expenditure module is the core of the macroeconomic model, and the systematically balanced macro frame is calculated together with the potential growth rate and the consumer price index, etc. Then, the economic activity indicators, etc. with direct and indirect impact on energy demand are sought.

Real Expenditure Module

Assuming the Keynesian model, obtains real GDP as the sum total of separate estimates for each component.

－Private demand: Private consumption, residential capital formation and non-residential capital formation

Public demand: Government expenditure and public capital formation

External demand: Export and import

Wage-Price Module

Estimates general prices based on external factors (exchange rates, crude oil prices, etc.) and internal factors (supply-demand gap, etc.).

－Wages, corporate goods price index, consumer price index and GDP deflators

Nominal Expenditure/Income Distribution/Fiscal Policy Module

National income is distributed to individuals, corporations and the government through taxation and subsidies, etc. In addition, fiscal policy is balanced through government expenditure and taxes.

Production Module

Estimates key material production and industrial production index for energy demand estimates.

―Material production: Crude steel, ethylene, cement, paper and pulp

Industrial production index: Foods, textiles, paper and pulp, chemicals, non-metallic minerals, iron and steel, non-ferrous metals, metal machinery, etc.

Commercial Sector Floor Area Module

Estimates the total floor space for all types of industry in the commercial sector

― Offices, eating and drinking services, retailers, schools, hotels, hospitals and welfare facilities, entertainment facilities, etc.

Transport Demand Module

Estimates transport demand by transport mode (passenger kilometers, ton kilometers). For motor vehicles, also estimates passenger vehicles, freight vehicle ownership and number of vehicles sold.

―Passenger kilometers and ton kilometers for automobiles, railways, ships, and aircraft

Number of passenger vehicles and freight vehicles sold by class

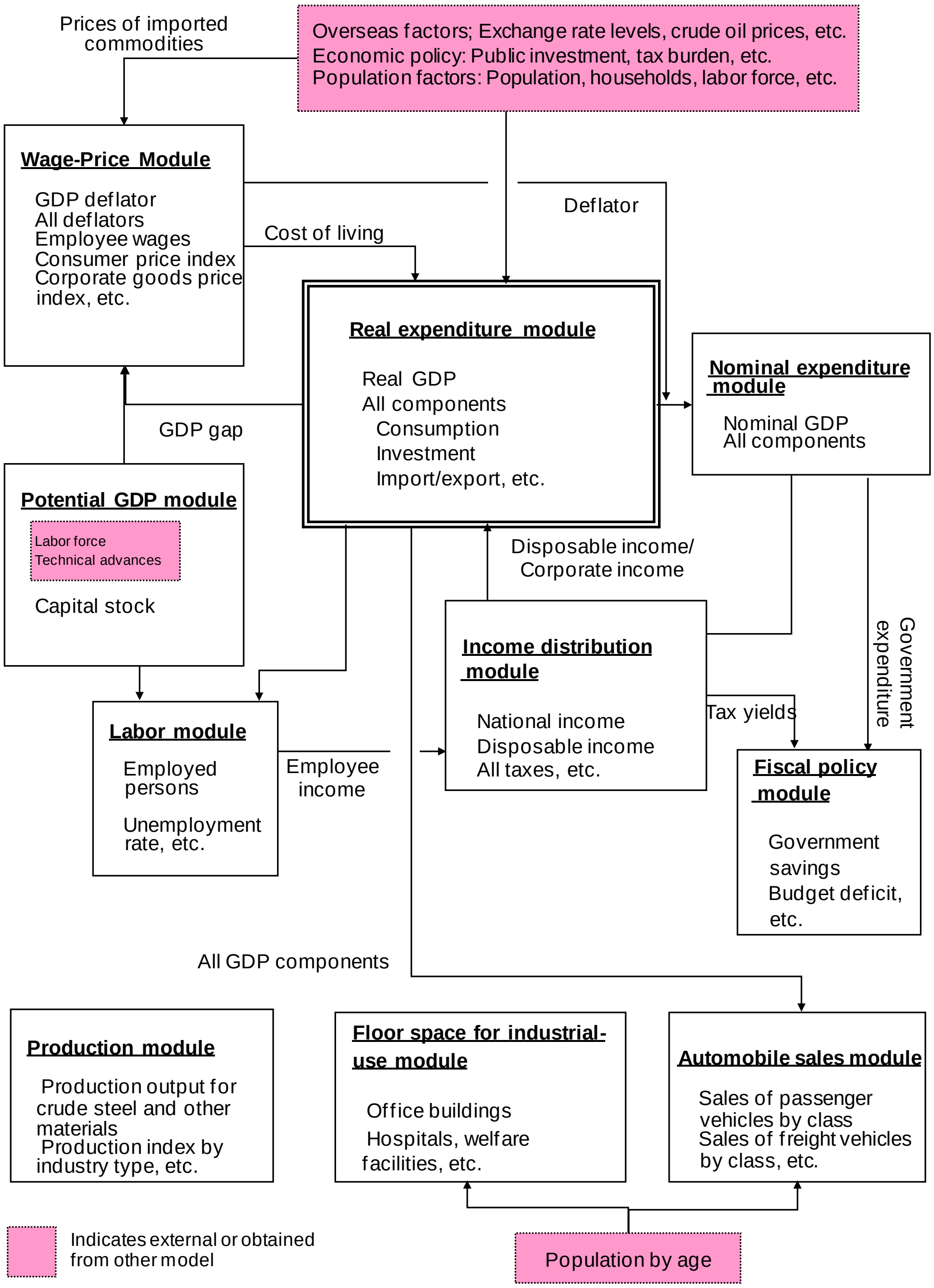

Figure 2-1 Outline of the macroeconomic model

(3) The energy supply-demand model

The energy supply-demand model consists of the final energy consumption sector (industry, buildings, transport and non-energy use), the energy transformation sector (power generation, oil refining, city gas production, etc.) and the primary energy supply sector. Based on the energy balance table, it is possible to describe the outlook for the entire supply-demand balance. However, for this study, the role of the energy supply-demand model is limited to calculating energy service demand. The amount of energy consumed through energy choices is calculated based on the technology evaluation model described next.

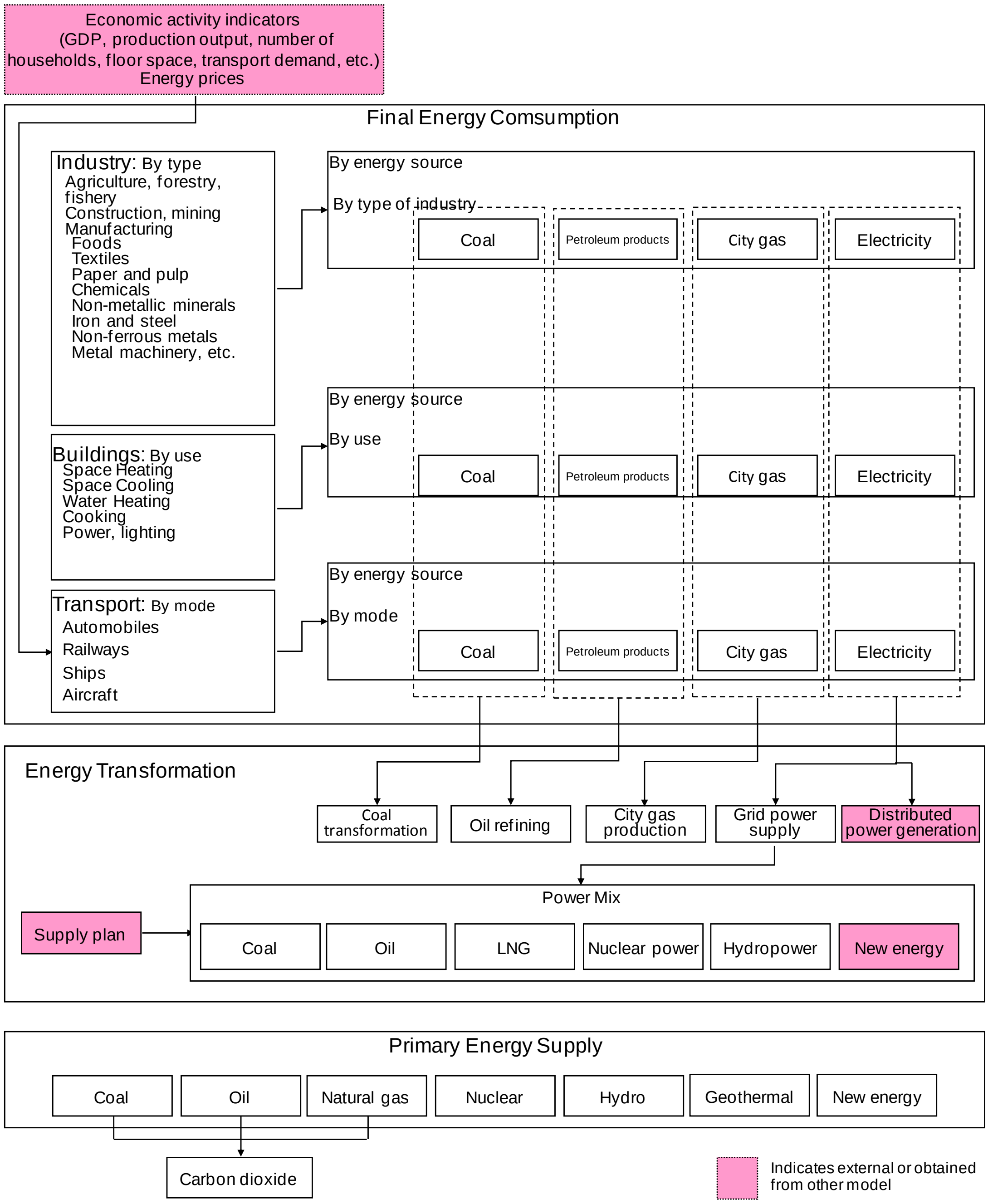

Figure 2-2 Outline of the energy supply-demand model

(4) The technology evaluation model (MARKAL model)

The MARKAL model is a linear programming model for estimating a future energy system that can be created and operated at minimum cost under given economic and technological scenarios and constraints. In this model, the total system cost is the objective function that is subject to optimization, which is defined as the total sum of equipment cost, fuel cost, operation and maintenance costs, etc. for each technology. The MARKAL model is structurally similar to actual energy systems, consisting of energy supply and demand technologies. Energy supply technologies mine primary energy and transform it into secondary energy in order to provide final energy to energy demand technologies. Energy demand technologies consume final energy to provide energy services. The amount of introduction and operation for each energy technology is determined as the result of calculations to minimize total system costs. By building up the results of the calculations, it is possible to estimate energy supply-demand structures, CO_2 emissions and total system costs.

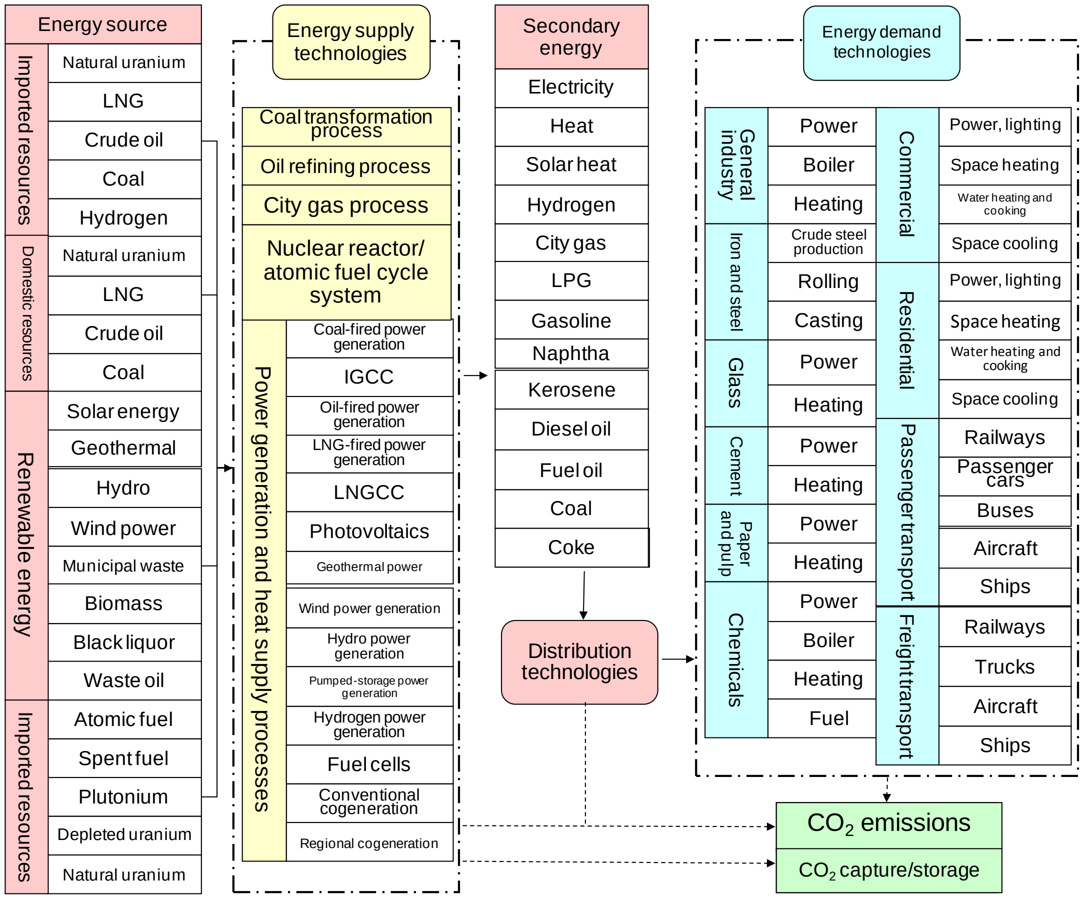

Figure 2-3 MARKAL model structure

2-2 Assumptions

(1) Macro-economic assumptions and energy service demand

Estimation process for this study: As indicated in Table 2-1, preconditions (initial values) corresponding to sequence 0 are set based on past studies [2], including population and other macro-economic indicators.

Table 2-1 Macroeconomic assumptions

Facts and Assumptions	Historical			Projection			
	1990	2000	2010	2020	2030	2040	2050
Real GDP (trillion yen in 2000 prices)	453.6	505.6	538.5	581.6	623.2	664.9	697.6
Population (million)	123.6	126.9	128.1	124.1	116.6	107.3	97.1
GDP per capita (10,000 yen/person in 2000 prices)	367	398	420	469	534	620	719
Number of motor vehicles owned (million)	57.8	72.5	75.2	73.9	69.1	63.4	57.1
Floor space for commercial use (million m^2)	1,285	1,656	1,834	1,964	1,966	1,938	1,881

Annual average growth rate (%)	Historical			Projection			
	1990/2000	2000/2010	2010/2020	2020/2030	2030/2040	2040/2050	2010/2050
Real GDP	1.09	0.63	0.77	0.69	0.65	0.48	0.65
Population	0.26	0.09	-0.31	-0.62	-0.83	-0.99	-0.69
GDP per capita	0.82	0.54	1.09	1.32	1.49	1.49	1.35
Number of motor vehicles owned	2.30	0.36	-0.17	-0.66	-0.86	-1.04	-0.69
Floor area for industrial use	2.57	1.03	0.69	0.01	-0.15	-0.30	0.06

Based on these preconditions, we used the energy supply-demand model and derived the energy service demands that provide the input data for the MARKAL model in the preliminary stages of the iterative calculation. The results are shown in Figure 2-4.

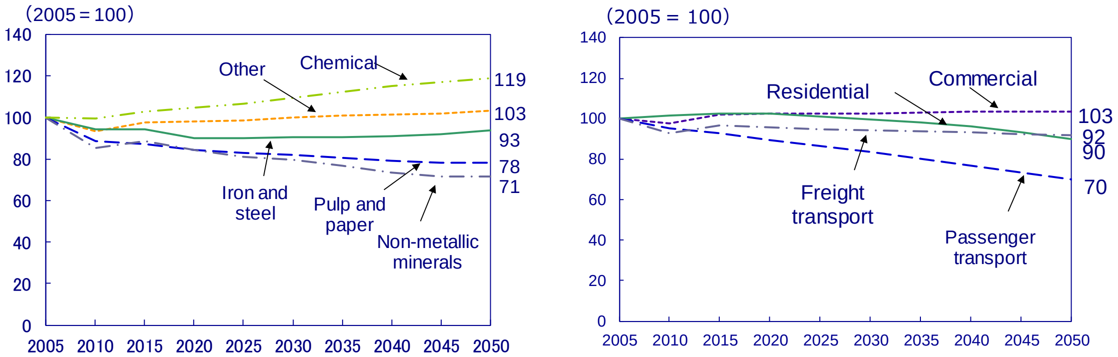

Figure 2-4 Energy service demands up to 2050

(2) Energy import prices

We referred to [2] for assumptions about fossil fuel prices. While demand for oil continues unabated with the focus on Asia, the decline rate of existing oil fields is rising and conditions for exploration are growing increasingly tough. Considering this situation, we assume that crude oil prices will rise in the long term. In the near term, the import prices for LNG to Asia, including Japan, are conventionally set by linking to crude oil, and the trend is for high prices worldwide. However, expecting future imports of LNG derived from North American shale gas, we assume that the relative ratio with crude oil will decline in the future. As for coal, we assume a gradual rise in line with the increase of crude oil prices.

Concerning methods of supplying hydrogen, there are studies underway of “CO_2-free hydrogen,” which would be manufactured from low-grade coal in Australia for transport to Japan. In the method, the CO_2

emitted during the manufacturing process would be captured and stored using carbon dioxide capture and storage (CCS) technologies. The NEDO report [3] contains estimates of its cost (import price). The estimate includes all costs for hydrogen production from lignite, underground storage of CO_2 by means of CCS technology, and transport to Japan in the form of liquefied hydrogen. According to the report, the CIF price for imported hydrogen is expected at JPY30/Nm^3 (USD0.33/Nm^3). Table 2-2 indicates assumed fossil fuel prices including hydrogen (2011 import CIF prices).

The exchange rate is fixed at 90 yen/dollar going forward, and the discount rate is assumed to be 3%.

Table 2-2 Assumed fossil fuel and hydrogen pricess ($2011, import CIF prices)

		2011	2030	2050
Crude oil	(USD/bbl)	109	122	130
LNG	(USD/t)	762	739	721
Steam coal	(USD/t)	138	139	148
Hydrogen	(USD/Nm^3)	-	0.33	0.33

(3) Power generation technologies

Concerning power generation technologies, the costs and efficiencies were assumed in accordance with the estimation by the Costs Verification Committee [4]. The specifics are outlined in Table 2-3. The power generation costs estimated by the Committee feature a wide gap between the upper and lower limits, especially for renewable energy. This study applies the average value between the two limits. As for thermal (fossil-fuel fired) power generation, the unit construction cost, operating and maintenance costs, and other costs shown in the report were adopted, and then the projections in Table 2-2 were adopted for the costs of purchasing fossil fuels. The conversion factors for nuclear power generation and renewable energy generation (power generation efficiency) conform to those adopted in the IEA's energy balace tables.

Table 2-3 Assumptions regarding power generation technologies

	Capacity factor (%)	Power generation efficiency (HHV, %)	Initial investment cost (USD/kW)	Fixed operation and management cost (USD/kW/Year)
Coal-fired	70	42-48	2,556-3,194	94-116
LNG-fired	70	51-57	1,333	51
Oil-fired	50	39	2,111	74
Nuclear	80	-	3,889	206
Hydro	45	-	9,444	97
Solar PV	12	-	2,261-5,000	73-123
Wind	20	-	2,928-3,056	113-118
Geothermal	80	-	8,889	361
Hydrogen	70	57	1,333	51
Gas reformed fuel cell	70	37	5,556-88,889	27-828

With regard to nuclear power, it is assumed that reactors conforming to the regulatory standards will start operations in sequence. The No. 3 reactor at the Shimane power plant and the Oma power plant, currently under construction, are also expected to start operations before 2020. The nuclear reactors are assumed to be shut down after an average service life of around 45 years. It is also assumed that nuclear power generating capacity will be maintained at a certain level from 2035 onward as a result of the construction of new nuclear reactors. The power plant capacity would be "45-year utilization + new construction" as indicated in Table 2-5.

Concerning power generation from renewable energy, assumptions are made in accordance with the estimates of the Energy and Environment Council [6]. However, in view of the introduction costs and feasibility, it is assumed that renewable energy will constitute 25% of power generation mix in 2030 and that it will continue to expand steadily until 2050. The assumptions on renewable energy power generation are outlined in Table 2-4.

With regard to hydrogen-fired power generation, 2030 is assumed to be a feasible year for introduction. The construction cost is assumed to be equivalent to LNG-fired power generation (JPY120,000/kW) while power generation efficiency is assumed at 57% (HHV, and assumed same efficiency as LNG-fired power generation in 2030).

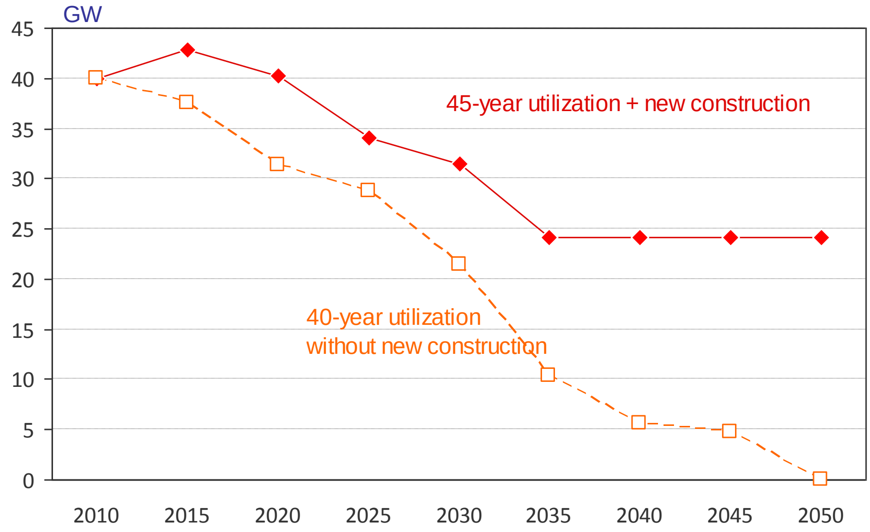

Figure 2-5 Assumptions on nuclear power generating capacity

Table 2-4 Assumptions on renewable energy

Unit: TWh

	2010	2030	2050
Hydroelectric power generation	89	118	118
Solar power generation	4	56	106
Wind power generation	4	33	50
Geothermal power generation	3	17	31
Biomass power generation, etc.	14	34	52
Total	115	258	356

(4) CCS

The CCS cost was set based on the report [5] by the Research Institute of Innovative Technology for the Earth (RITE) (Figure 2-6). It shows energy consumption associated with CO_2 capture, as well as the costs of capital investment and operation and maintenance for coal-fired power generation with CCS, which we adopted as the basic assumptions for CCS technology. Concerning LNG-fired power generation with CCS, the costs and electricity consumption per quantity of captured carbon were assumed to be the same as the case of coal-fired.

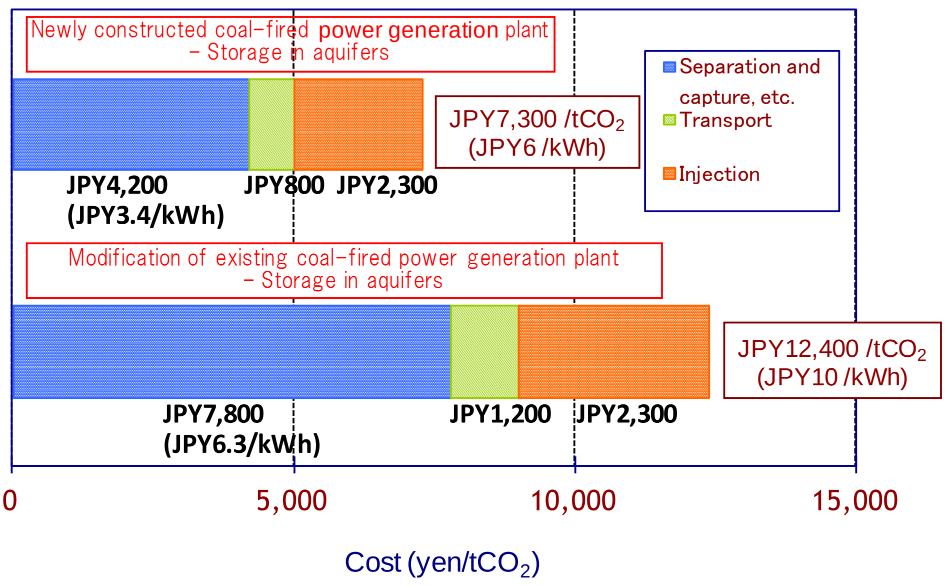

Figure 2-6 CCS cost estimation by RITE

3. Impact of Ambitious CO_2 Emission Reduction on the Economy and the Supply and Demand of Energy

In this section, we perform quantitative assessments of the impact of ambitious CO_2 emission reduction on the economy and supply and demand of energy in the future by establishing the three cases outlined below, without assuming that hydrogen is introduced in any of the three cases.

Case 0	No CO_2 constraints are set
Case 65%	CO_2 constraints are set to a 65% reduction from the 1990 level by 2050
Case 70%	CO_2 constraints are set to a 70% reduction from the 1990 level by 2050

3-1 Real GDP

Figure 3-1 outlines real GDP (in 2000 prices) for each scenario. For the Case 0, where no CO_2 constraints are set, real GDP in 2050 would be JPY698 trillion . This represents an average growth rate of 0.65% from 2010. On the other hand, for the Case 65% and the Case 70%, where CO_2 constraints are present, economic growth is sluggish compared to the Case 0, with real GDP in 2050 at JPY669 trillion (down 4.0% compared to the Case 0) and JPY637 trillion (down 8.6% likewise) respectively. This means that 18% and 38% of the economic growth for the period 2010 to 2050 expected under the Case 0 would be lost due to the reduction of CO_2 emissions in the Case 65% and the Case 70%. Although the difference in CO_2 emissions reduction between the Case 65% and the Case 70% is 5% compared to the 1990 level, or about 53 Mt, the economic burden imposed by the difference is large. Since only extremely costly reduction options remain for the additional reduction from 65% to 70%, the carbon price for achieving an additional 1% reduction is extremely high. Therefore, additional reduction rates generate nearly the same rate of GDP loss.

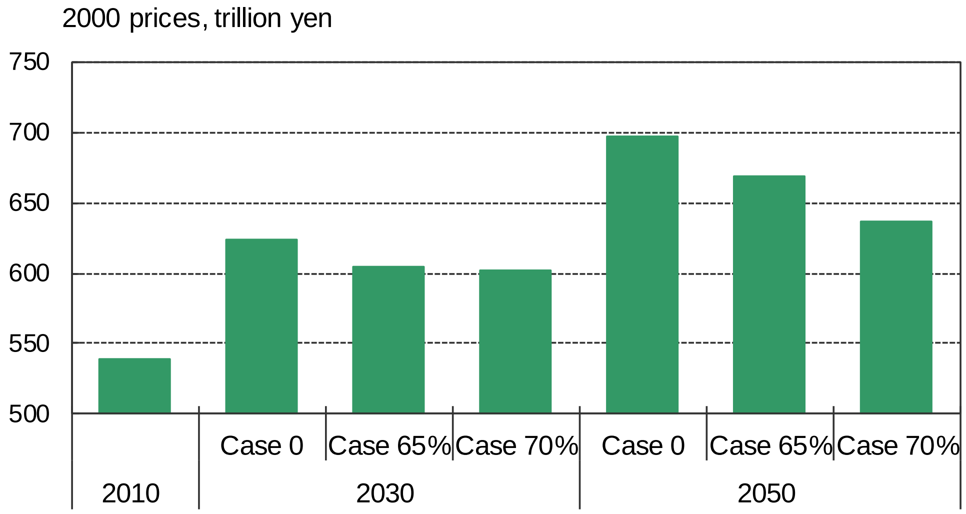

Figure 3-1 Real GDP

Figure 3-2 shows real GDP variations (2050) from the Case 0 for the Case 65% and the Case 70%, decomposed by components. For both the Case 65% and the Case 70%, private-sector consumption contributes most to the reduction in real GDP, followed by private-sector capital investment. The reduction in private-sector consumption accounts for 44% and 49% of the net reduction in GDP for the respective cases. The principal cause of the reduction in private-sector consumption is the rise in fossil fuel and electricity prices due to the impact of carbon price, which leads to a reduction in real disposable incomes and diminished economic activity. With the rise in domestic cost of living, the cost of imported goods becomes relatively cheap, but when the impact of reduced income takes effect, imports also decrease (contributes positively to GDP). Exports are reduced as the rise in the cost has a debilitating effect on international competitiveness. As for government consumption and government investment, there is no variation between the cases because the same values are provided for each case.

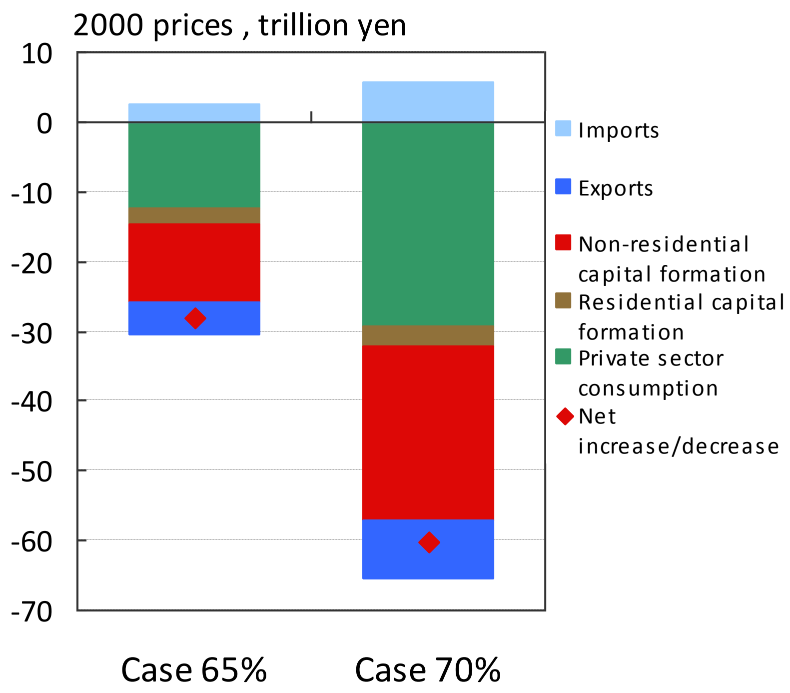

Figure 3-2 Contribution to real GDP variation (2050: variations from the Case 0)

3-2 Energy-related investments

The amount of cumulative energy-related investment to be made by 2050 for each case is shown in Figure 3-3. For the Case 65% and the Case 70%, where CO_2 constraints are present, the amount of cumulative investment is reduced compared to the Case 0 for the reasons outlined below.

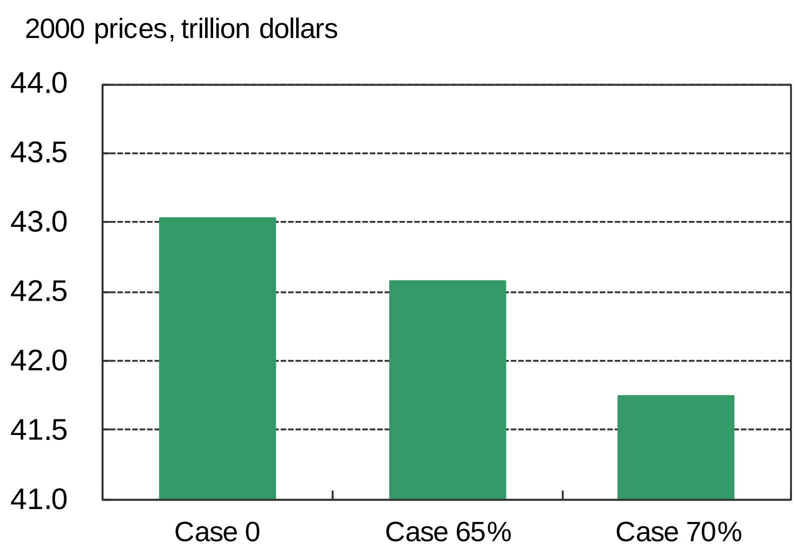

Figure 3-3 Cumulative energy-related investments by 2050

As indicated in Figure 3-4, compared to the Case 0, cumulative investment for all sectors, with one exception, is reduced for the Case 65% and the Case 70%. This is because the decline in investment is higher than the increase in investment thourgh advances in energy switching and the introduction of energy-effective facilities. As a result of the CO_2 constraints, reduced real disposable income and diminished economic activity caused the decline of energy-related investment.

Looking at each sector, the investments for both the Case 65% and the Case 70% are reduced compared to the Case 0 for the transformation sector. One major factor is the loss of investment in coal fired IGCC power in the power generation sector. Also, with the reduction in energy demand due to diminished economic activity, investment in transport infrastructure for all types of energy is significantly reduced. If we look at the differences in investments by rate of reduction, the investment reduction is larger for the 70% reduction case than for the 65% reduction case. This is due to diminished investment in relatively costly renewable energy power generation, such as solar photovoltaics, because of the reduction in electricity demand for the 70% reduction case.

In the buildings sector, the amount of investment at the 65% reduction case is higher than for the Case 0. This is the result of rising demand for power and lighting as well as increased related investments with the advance of electrification in the residential as a strategy for cutting CO_2. On the other hand, there is a large reduction in investments at the 70% reduction case. Although the advance of electrification in the residential sector at the 70% reduction case works in the same way as for the 65% reduction case, the effect is to reduce demand due to lower real disposable income, and as a result there is a large drop in the amount of investment related to demand for power and lighting. As Figure 3-5 shows, the contribution of this investment is the highest at 67% among the changes in the amount of cumulative energy-related investment for the 65% reduction and 70% reduction cases.

In the transport sector, investment in gasoline-powered automobiles is reduced due to the CO_2 constraints, but since this is overtaken by increased investment in electric cars and natural gas-powered vehicles, there is a net increase in automobile investment. However, the decrease in demand for passenger aircraft due to decreases in real disposable income results in a large drop in related investment, with the amount of investment for the whole sector decreasing at both the 65% reduction and 70% reduction cases. Since demand for passenger aircraft decreases even more at the 70% reduction case than at the 65% reduction case, investment amount declines even further.

In the industrial sector, energy service demands are reduced due to shrinking economic activity, and as a result, the amount of investment is reduced. Iron and steel, and cement-related investments contribute much to the reduction.

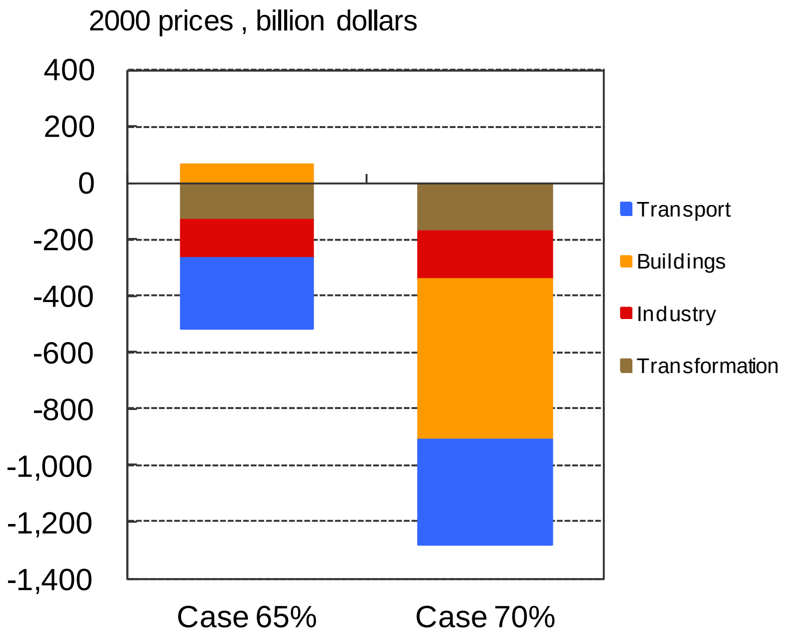

Figure 3-4 Contribution to changes in cumulative energy-related investments (changes from the Case 0)

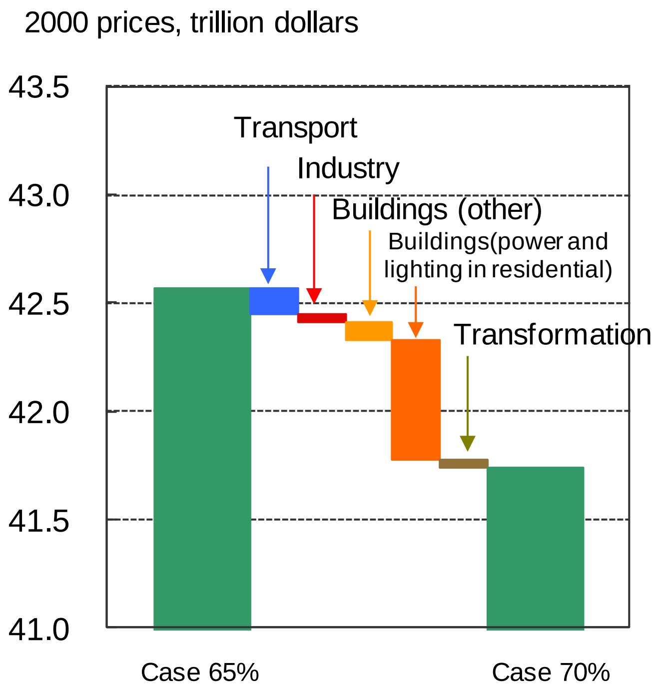

Figure 3-5 Contribution by sector to changes in cumulative energy-related investments (for cases of CO_2 reduction)

3-3 Fossil fuel import spending

Figure 3-6 outlines real import spending (in 2000 prices) for fossil fuels in 2050 for all cases.

For the Case 0, the import spending of fossil fuel imports in 2050 is JPY9.2 trillion. The share of coal, oil (including its products), and natural gas is 26%, 61% and 13% respectively. For the Case 65% and the Case 70%, where CO_2 constraints are present, economic activity will diminish with the impact of high carbon price, and import spending will decrease. The import spending are JPY8.9 trillion for the Case 65% (down 3.8% compared to the Case 0) and JPY8.4 trillion for the Case 70% (down 9.3% likewise). With advances in fuel alternatives due to CO_2 constraints, the share of coal in the import spnending will decrease (6% for the Case 65%, 2% for the Case 70%). On the other hand, the share of natural gas will increase to 34% for the Case 65% and 37% for the Case 70%.

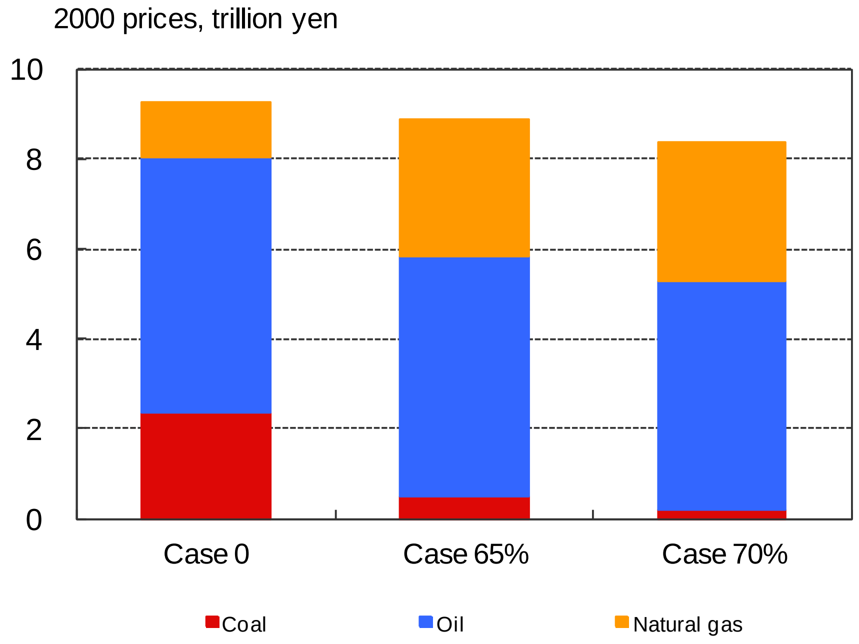

Figure 3-6 Fossil fuel import spending

3-4 Carbon and electricity prices

Figure 3-7 shows the carbon price (in 2000 prices) and the electricity price (in 2011 prices) in 2050 for all the cases.

The carbon price is USD423/tCO_2 for the Case 65% and USD1,154/tCO_2[1] for the Case 70%. The drastic rise in carbon price for the Case 70% means that the reduction measures set in the MARKAL model have almost reached their upper limits, and that extremely economically inefficient measures, even unrealistic ones, are needed for further reduction. Above all, since the value of this "upper limit for measures" also depends on the introduction of assumed potentials, including the introduction of renewable energy, it must be noted that carbon prices corresponding to a particular reduction rate are not absolute, but fluctuate

[1] Equivalent to JPY241 a liter (US$1=JPY90) of gasoline

significantly depending on changes in the preconditions.

The electricity price is obtained by weighting the unit cost of power generation for each method of power generation with the amount of power generation obtained in the MARKAL model, calculating the average cost for power generation and adding in the carbon price. Electricity prices in 2050 are JPY10.3/kWh for the Case 0, JPY13.5/kWh for the 65% reduction case and JPY20.2/kWh for the 70% reduction case.

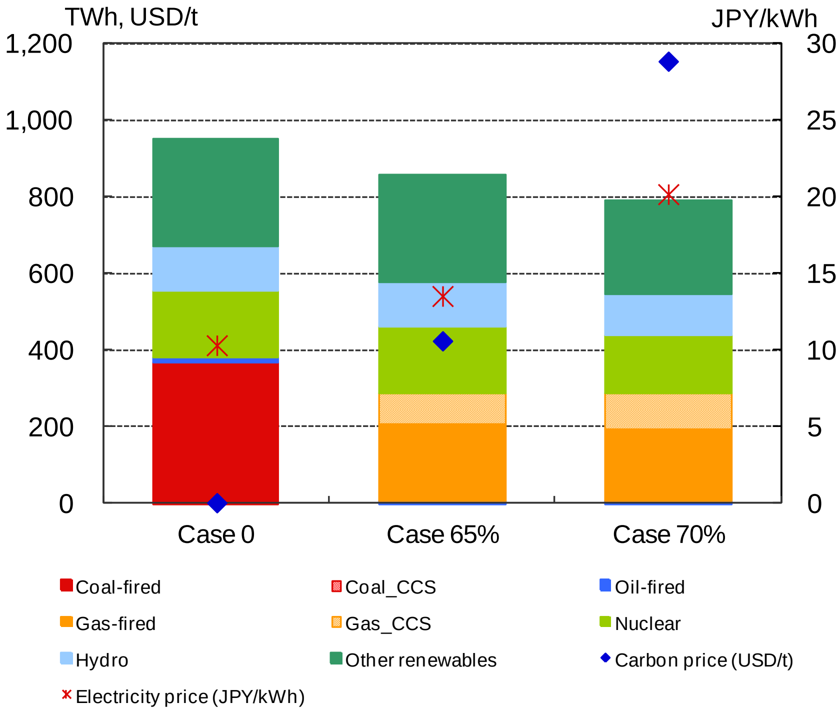

Figure 3-7 Power generation mix and carbon price, electricity price (2050)

3-5 Energy costs in the final consumption sector

Figure 3-8 shows energy costs for 2050 (in 2000 prices) and average energy prices (in 2000 prices) in the final consumption sector. Since the carbon prices indicated in Figure 3-7 are included in the energy prices at final consumption, there is a large increase in energy costs for the Case 65% and the Case 70% where CO_2 constraints are present. Whereas the energy cost for the Case 0 is JPY41.1 trillion, it is JPY46.1 trillion for the Case 65% (up 12% compared to the Case 0), and JPY52.3 trillion for the Case 70% (up 27% likewise).

Viewed by sector, energy costs increase substantially in the industrial sector where fossil fuels account for a large ratio of energy consumption. This is because carbon costs are added to wholesale prices for coal, etc. Energy costs for the industrial sector will increase by 46% for the 65% reduction case, and by 60% for the 70% reduction case compared to the Case 0.

The average price of energy (yen/Mcal) is derived by dividing energy costs with final energy consumption. The average energy price in 2050 is JPY23.0/Mcal for the Case 0, JPY29.3/Mcal for the Case 65% (up 27% compared to the Case 0), and JPY36.2/Mcal (up 57% likewise) for the Case 70%.

Similarly, the annual energy bill per household is calculated by dividing energy costs in the residential sector (excluding that for automobiles) with the number of households. Assuming that the number of households in 2050 is 45.7 million, the real annual energy bill per household (in 2000 prices) would be JPY204,000 for the Case 0, JPY202,000 for the Case 65% (down 1.1% compared to the Case 0), and JPY215,000 for the Case 70% (up 5.7% likewise). The decrease in energy bills for the Case 65% compared to the Case 0, and the small increase in the energy bill also for the Case 70% compared to the rise in average energy prices, are caused by a decline in energy consumption due to a decrease in real GDP of 4.0% for Case 65% over the Case 0, and a decrease of 8.6% for the Case 70%.

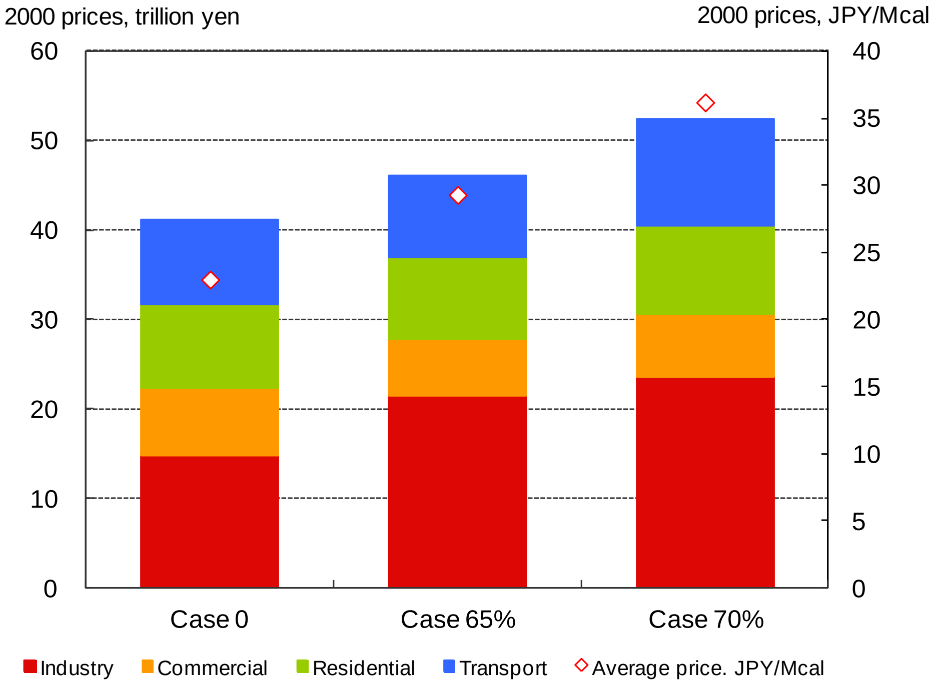

Figure 3-8 Energy costs and average prices at final consumption (2050)

3-6 Primary energy supply

The primary energy supply in each case is shown in Figure 3-9. Even in the Case 0, where CO_2 constraints are not set, the primary energy consumption will be reduced from 497 Mtoe in 2010 to 306 Mtoe in 2050, a decrease of 38%. In this case, cheap coal will be the major energy source. It should be noted that the dependence on coal continues to increase from 2010, reaching 36% in 2050, which is much higher compared with the Case 65% and the Case 70% with CO_2 constraints (8% and 3% in 2050, respectively). On the other hand, the shares of oil and natural gas have declined from the 2010 levels, reflecting the rise in crude oil and LNG prices. In the Case 0, the introduced amount of nuclear power will be 44 Mtoe in 2050, and that of renewable energy (excluding hydro) will be 48 Mtoe in the same year.

In the Case 65% and the Case 70%, where CO_2 constraints are set, primary energy consumption in 2050 will be 253 Mtoe (down 49% from 2010) and 226 Mtoe (down 55% from 2010), that is, 17% and 26%

below the level in the Case 0, respectively. In addition to an extremely strong emphasis on promoting energy conservation to ensure compliance with the tough restrictions on CO_2 emissions, carbon pricing will cause fossil fuel and electricity prices to rise, and with the resulting impact of diminished economic activity, the supply of primary energy will decrease. In addition, while the share of natural gas will rise to 24% and 27% respectively from 17% in 2010, the shares of oil and coal will decline significantly, i.e. fuel switching will take place to meet the CO_2 constraints.

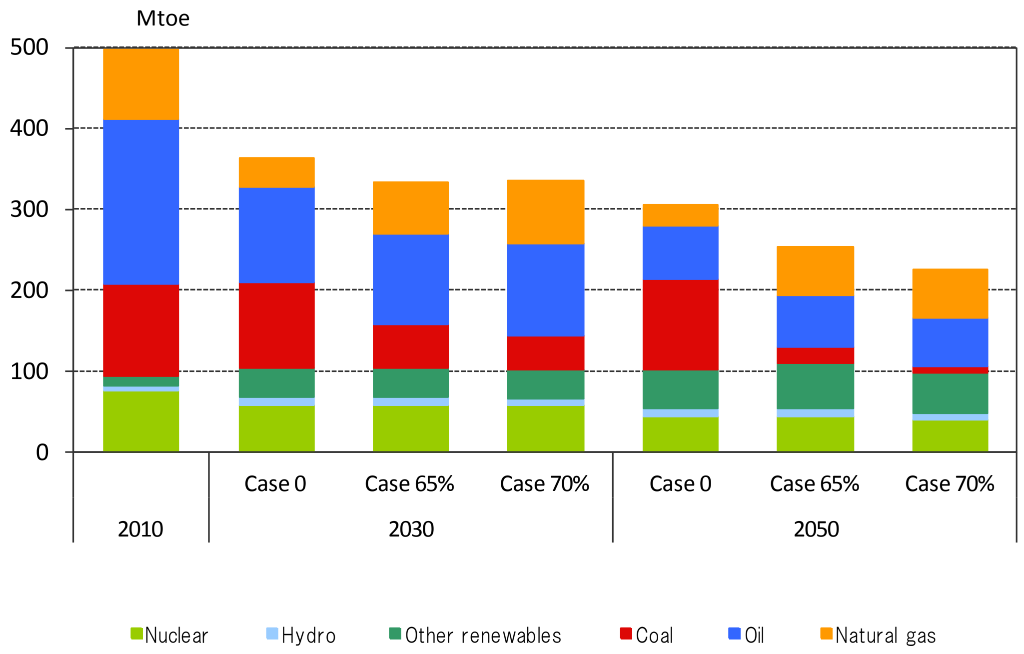

Figure 3-9 Primary energy supply

3-7 Final energy consumption

The final energy consumption for each case is shown in Figure 3-10. Compared with the final energy consumption of 325 Mtoe in 2010, the consumption in 2050 will decline to 197 Mtoe for the Case 0 (down 39%), 165 Mtoe for the Case 65% (down 49%), and 148 Mtoe for the Case 70% (down 54%). While the consumption of fossil fuel, including petroleum products, decreases significantly from 2010 to 2050, electricity consumption will not decrease substantially because low-carbon electricity will be used to reduce CO_2 emissions. As a result, the electrification rate in the final energy consumption for 2050 will increase from 27% in 2010 to 40% for the Case 0, 43% for the Case 65%, and 44% for the Case 70%. It should be noted that the electrification rate will be higher for the Case 65% and the Case 70% than for the Case 0 without CO_2 constraints.

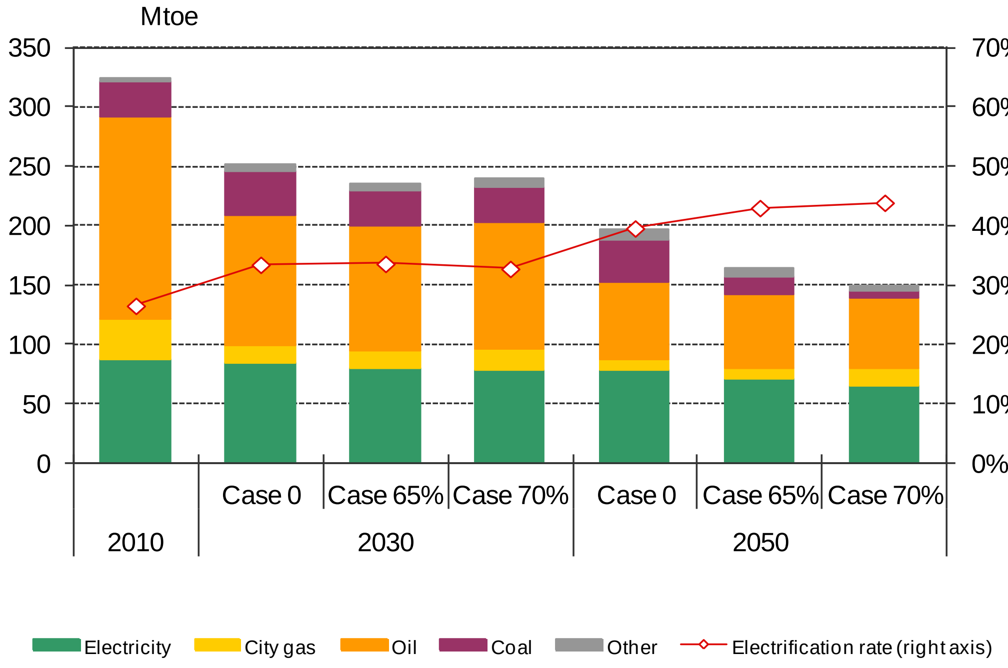

Figure 3-10 Final energy consumption

3-8 Power generation

Figure 3-11 shows the power generation mix for each case. Total electricity generation significantly decreases from 1,091 TWh in 2010 to 953 TWh in 2050 for the Case 0 (down 13%), 860 TWh for the Case 65% (down 21%), and 791 TWh for the Case 70% (down 28%) respectively. The main cause of the decline is a drop in energy service demand due to diminishing economic activity.

If we look at the power generation mix, the power generation from nuclear power and renewable energies, where the input amounts are fixed, is almost equal (for the Case 70%, the ratio to total power generattion is fixed to be equal with the Case 0), while the mix of the remaining thermal power generation varies. Where there are no CO_2 constraints, coal-fired power generation will increase, with its share rising from 24% in 2010 to 39% in 2050. Meanwhile, in the Case 65% and the Case 70%, where CO_2 constraints are set, coal-fired power generation will be zero in 2050, being replaced with LNG-fired power generation (with/without CCS). Coal CCS will not be introduced due to the high costs.

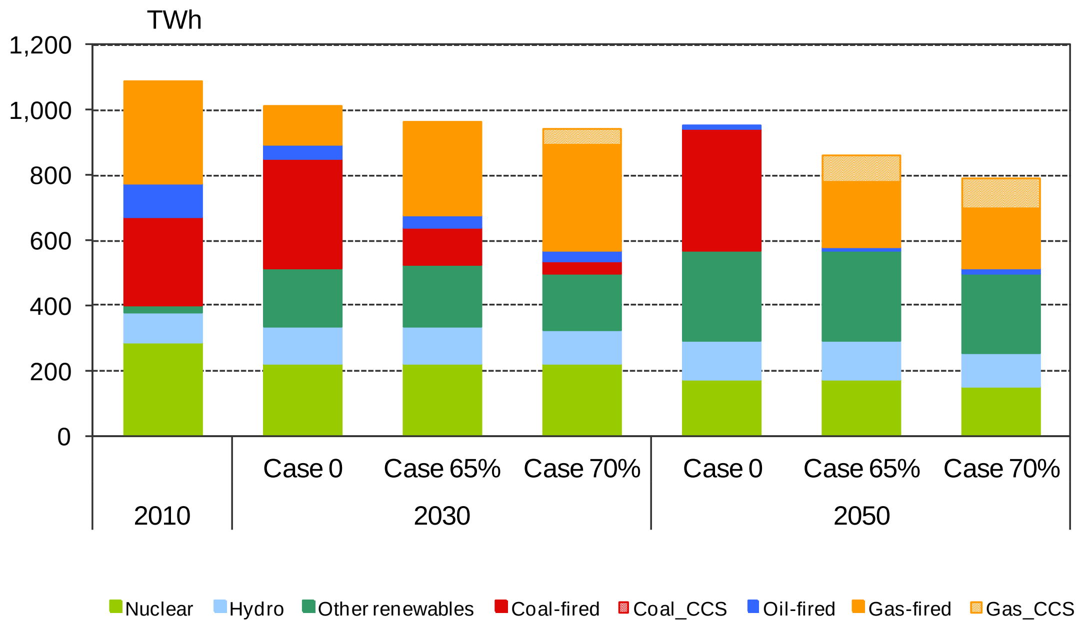

Figure 3-11 Power generation mix

3-9 CO_2 emissions

Figure 3-12 shows the outlook for energy-related CO_2 emissions. In the Case 0, where there are no CO_2 constraints, CO_2 emissions will decline significantly from the 2010 level, down 39% to 683 Mt in 2050. Factors behind this trend include reduced energy consumption, which is also assumed for the Case 0, and the mass introduction of renewable energy generation.

For the Case 65% and the Case 70%, where CO_2 constraints are imposed, CO_2 emissions will be significantly reduced for the power generation and the industry in both cases.

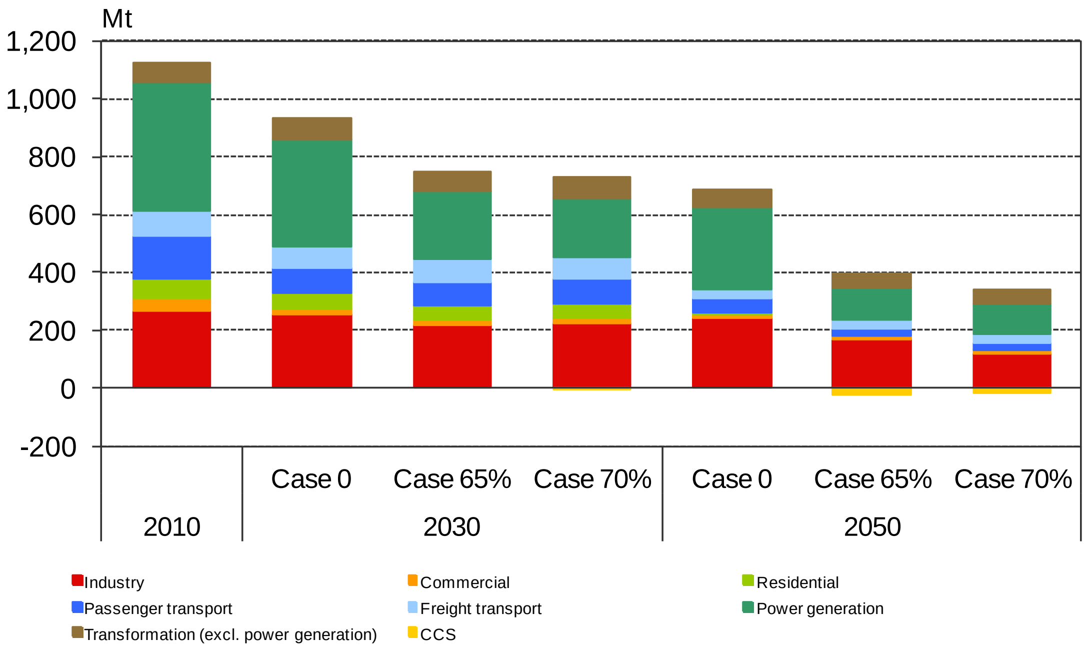

Figure 3-12 Energy-related CO_2 emissions

4. Mitigating the Burden of Ambitious CO_2 Emission Reductions through the Use of Hydrogen

In this section, we perform quantitative assessments of the extent to which hydrogen use would mitigate the impact on the economy and energy supply-demand of the ambitious CO_2 reductions presented in chapter 3. The introduction of hydrogen is expected for these two additional cases.

Case 65%_with hydrogen:

Introduction of hydrogen is allowed, and CO_2 constraints are set to a 65% reduction from the 1990 level by 2050

Case 70%_with hydrogen:

Introduction of hydrogen is allowed, and CO_2 constraints are set to a 70% reduction from the 1990 level by 2050

4-1 Real GDP

Figure 4-1 outlines real GDP in 2050 (in 2000 prices) for the cases where CO_2 constraints are set. Real GDP increases for cases where the introduction of hydrogen is expected (the cases “with hydrogen”) compared to cases where the introduction of hydrogen is not expected (the cases “without hydrogen”). Real GDP for cases with hydrogen is JPY673 trillion for the 65% reduction case (up 0.6% compared to the case without hydrogen), and JPY665 trillion for the 70% reduction case (up 4.3% compared to the case without hydrogen). 18% and 38% respectively of the economic growth expected under the Case 0 for the period from 2010 to 2050 would be lost due to the reduction of CO_2 emissions for the Case 65% and the Case 70% without hydrogen, but for the Case 65%_with hydrogen and the Case 70%_with hydrogen, the loss would be mitigated to 15% and 20% respectively.

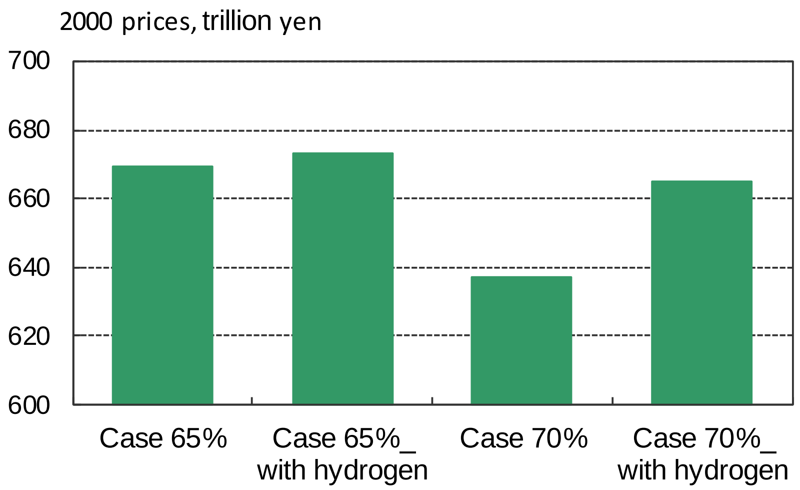

Figure 4-1 Real GDP (2050)

Figure 4-2 shows real GDP variations (2050) from the Case 0 for all cases with CO_2 constraints, decomposed by components. Compared to cases without hydrogen, the cases with hydrogen mitigate the amount of decline of all components that make negative contributions to GDP variations. Among them, the mitigation of the decline is conspicuous for private capital formation and private consumption, which are major components of GDP. The main reason for the mitigation is that the introduction of hydrogen will lower carbon prices, which, in turn, will raise disposable income or expand economic activity, compared to the cases without hydrogen.

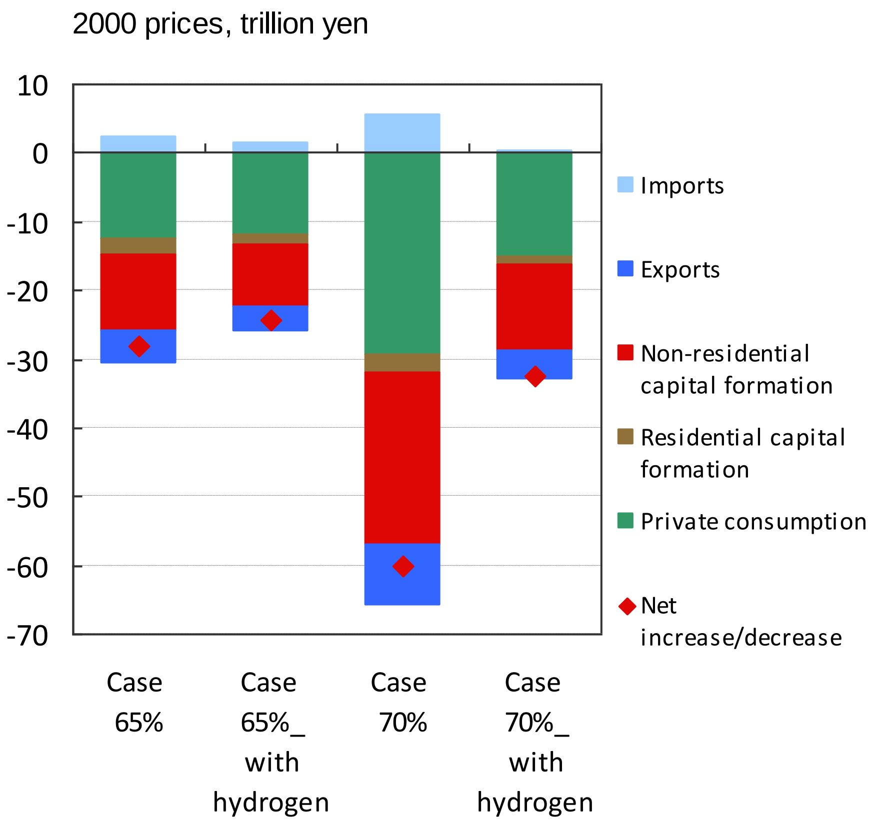

Figure 4-2 Contribution to real GDP variation (2050: variations from the Case 0)

4-2 Energy-related investments

Figure 4-3 shows cumulative energy-related investments (in 2000 prices) by 2050 for each case where CO_2 constraints are set. The investment amount for the Case 65%_with hydrogen is USD42.9 trillion, which is an increase of 0.8% compared to the USD42.6 trillion for the Case 65%. In contrast with the 65% reduction cases, the investment amount for the Case 70%_with hydrogen is USD41.6 trillion, which is a decrease of 0.3% compared to USD41.7 trillion for the Case 70%.

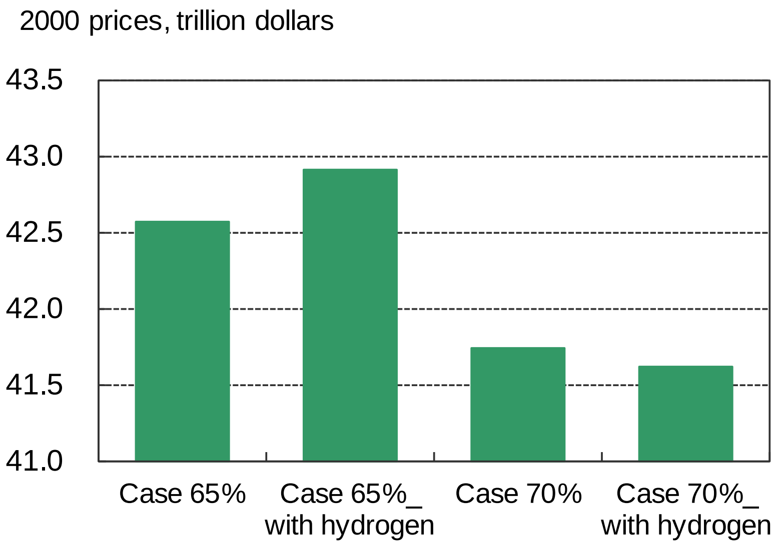

Figure 4-3 Cumulative energy-related investments by 2050

Figure 4-4 shows the changes from the Case 0 in the cumulative investments by sector for respective cases where CO_2 constraints are set. Figure 4-5 also shows changes in investments depending on the absence or presence of hydrogen for 65% reduction and 70% reduction (difference between cases with and without hydrogen).

For the Case 65%_with hydrogen, there is a significant increase in investment in the buildings sector compared to the case without hydrogen (increase of USD316 billion). This is the result of increased demand for power and lighting in the residential compared to the Case 65% because of an increase in real disposable income due to lower carbon price for cases with hydrogen. Related investment increases due to the growth in demand and, as a result, the investments in the private sector increase.

For the Case 70%_with hydrogen, there is a significant negative contribution to the investments in the transport sector compared to the case without hydrogen. For cases without hydrogen, CO_2 reduction in the power generation sector is more difficult because hydrogen is not available. On the other hand, although investment in electric vehicles and automobiles powered by city gas would make headway to attain the strict constraints of a 70% reduction, investment in the transport sector would not advance for cases with hydrogen because it is relatively easy to reduce CO_2 in the power generation sector through hydrogen-fired power generation.

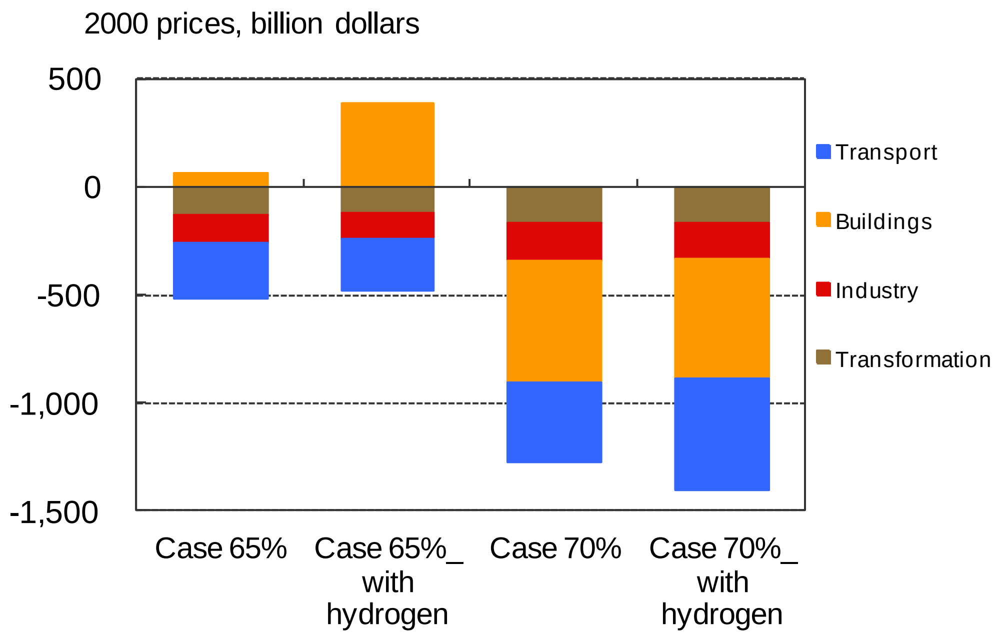

Figure 4-4 Contribution to changes in cumulative energy-related investments (changes from the Case 0)

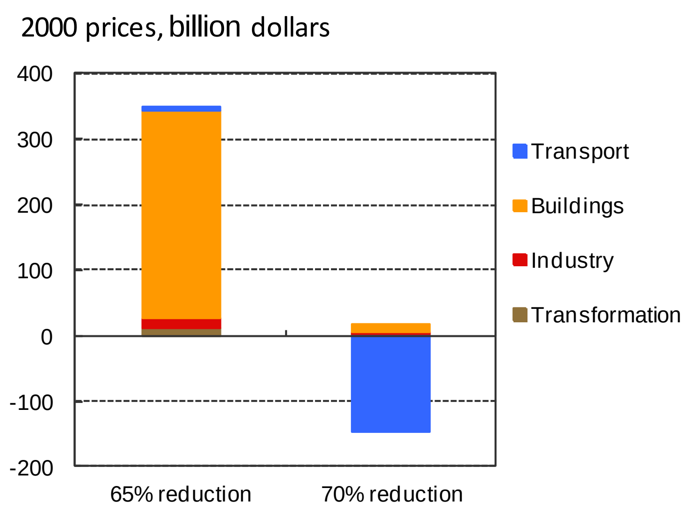

Figure 4-5 Changes in energy-related investments due to presence or absence of hydrogen introduction (2050: difference between with hydrogen case and without hydrogen case)

4-3 Fossil fuel and hydrogen import spending

Figure 3-6 outlines import spending (in 2000 prices) for fossil fuels and hydrogen in 2050 for all cases where CO_2 constraints are set. For cases where hydrogen introduction is allowed, the import spending are JPY9.4 trillion for the 65% reduction and JPY10.6 trillion for the 70% reduction, which represent increases of 5% and 26% respectively in the reduction rate compared to cases where hydrogen introduction is not allowed. This is because energy consumption increases in the cases where economic activity expands due to lower carbon prices. This increase in import spending, however, does not necessarily mean the same amount of additional outflow of national wealth. Where hydrogen energy development in Australia is concerned, the expectation is that Japan will export machinery in many parts of the project and retain an interest. If a 50% share of the payments for hydrogen imports returns to Japan through a variety of channels, the import spending from the aspect of national wealth outflow (import figures except the area shaded with diagonal lines in Figure 4-6) will be at the same level as the JPY9.2 trillion for the Case 0.

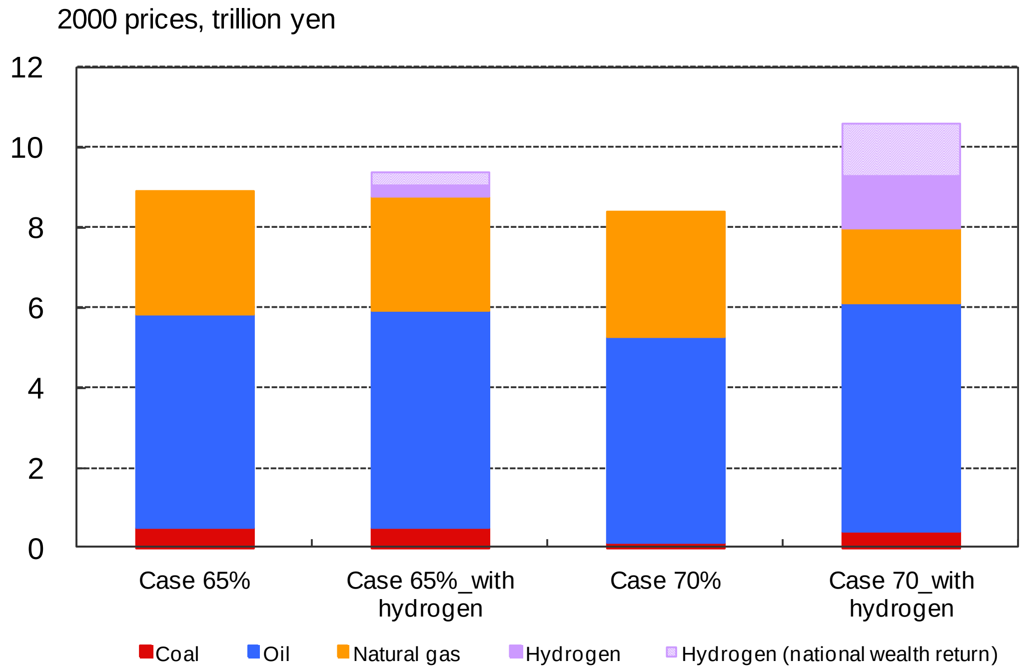

Figure 4-6 Fossil fuel and hydrogen import spending

4-4 Carbon and electricity prices

Figure 4-7 shows carbon prices (in 2000 prices) and electricity price (in 2011 prices) in 2050 for all cases where CO_2 constraints are set.

The carbon prices are USD340/tCO_2 for the Case 65%_with hydrogen, and USD539/tCO_2 for the Case 70%_with hydrogen, with a reduction rate of 20% and 53% respectively compared to cases where hydrogen introduction is not allowed. The decline in the carbon prices is reflected in the prices of fossil fuel and electricity, bringing about the aforementioned increase in real disposable income and expansion of economic activity, etc.

The electricity price in 2050 for the Case 65%_with hydrogen is JPY14.0/kWh, which is a rise of JPY0.5/kWh compared to the case without hydrogen. The reason for the rise in the average electricity price, despite cheaper carbon prices for cases with hydrogen than for cases without hydrogen, is that the unit cost of gas-fired and most renewable power generation is cheaper than that of hydrogen-fired power generation. For the Case 70%_with hydrogen, the electricity price is JPY15.8/kWh, which is a drop of JPY4.4/kWh from JPY20.2/kWh for the case without hydrogen. This is a reflection of the fall in carbon prices.

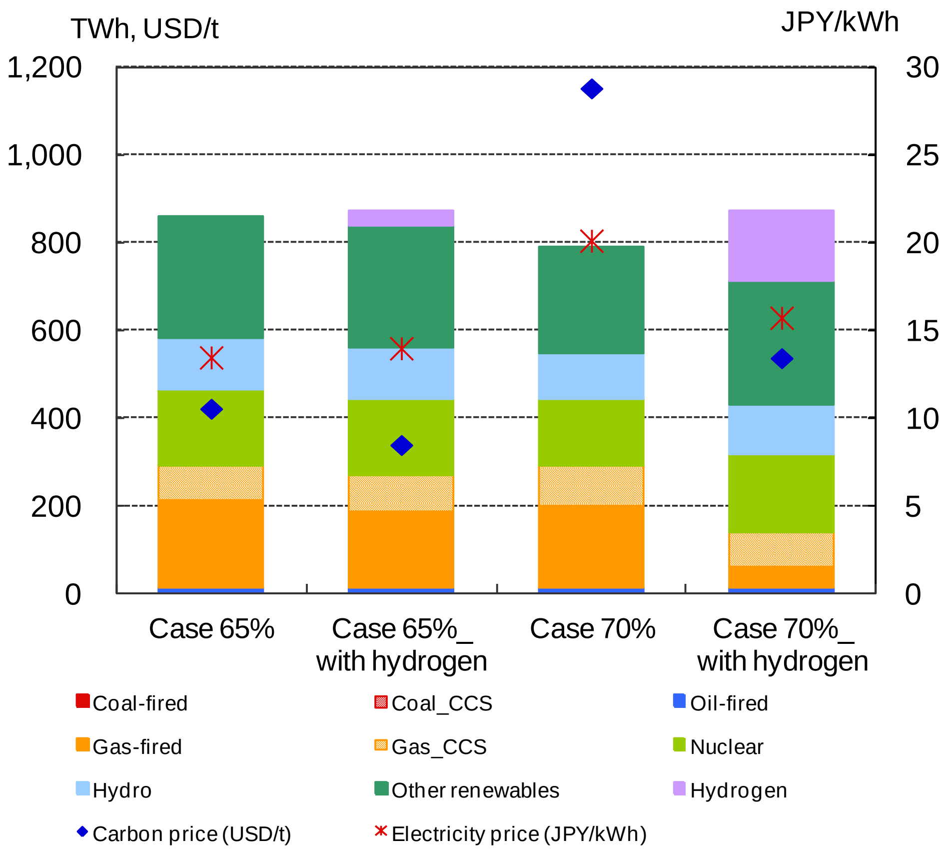

Figure 4-7 Power generation mix, carbon price, and electricity price (2050)

4-5 Energy costs in the final consumption sector

Figure 4-8 shows real average energy prices (in 2000 prices) and real energy costs (in 2000 prices) in the final consumption sector in 2050 for all cases where CO_2 constraints are set. The energy cost for the Case 65%_with hydrogen is JPY44.8 trillion, which is a decrease of 2.9% compared to the case without hydrogen. Similarly, the energy cost for the Case 70%_with hydrogen is JPY45.4 trillion, or a decrease of 13% compared to the case without hydrogen.

Looking at the energy costs broken down by sector, we see that there is a significant reduction in energy costs for the industry and transport that are heavily reliant on fossil fuel for which carbon prices have a direct impact on pricing. Compared to the case without hydrogen, the decrease for the Case 65_with hydrogen is JPY1.9 trillion (down 8.8%) in the industrial sector and JPY0.2 trillion (down 2.2%) in the transport sector. For the 70% reduction case, the mitigating effect of introducing hydrogen is even more conspicuous for the case with hydrogen, with a decrease of JPY3.1 trillion in the industrial sector (down 13%) and JPY2.4 trillion in the transport sector (down 20%).

Concerning average energy prices, hydrogen introduction also has a mitigating effect on cost. For the 65% reduction case, the average price is JPY27.9/Mcal for the case with hydrogen, which is a decrease of 4.7% from JPY29.3/Mcal for the case without hydrogen. Similarly, for the 70% reduction case, the average price for the case with hydrogen is JPY28.7/Mcal, or a 21% cost decrease from JPY36.2/Mcal for the case without hydrogen.

The real annual energy bill per household (in 2000 prices) is JPY214,000 for the Case 65%_with hydrogen (up 6.1% compared to the case without hydrogen), and JPY206,000 for the Case 70%_with hydrogen (down 4.6% compared to the case without hydrogen). The reason for the increase in energy bills in the 65% reduction case is that energy consumption increases with the increase in real disposable income and in electricity prices.

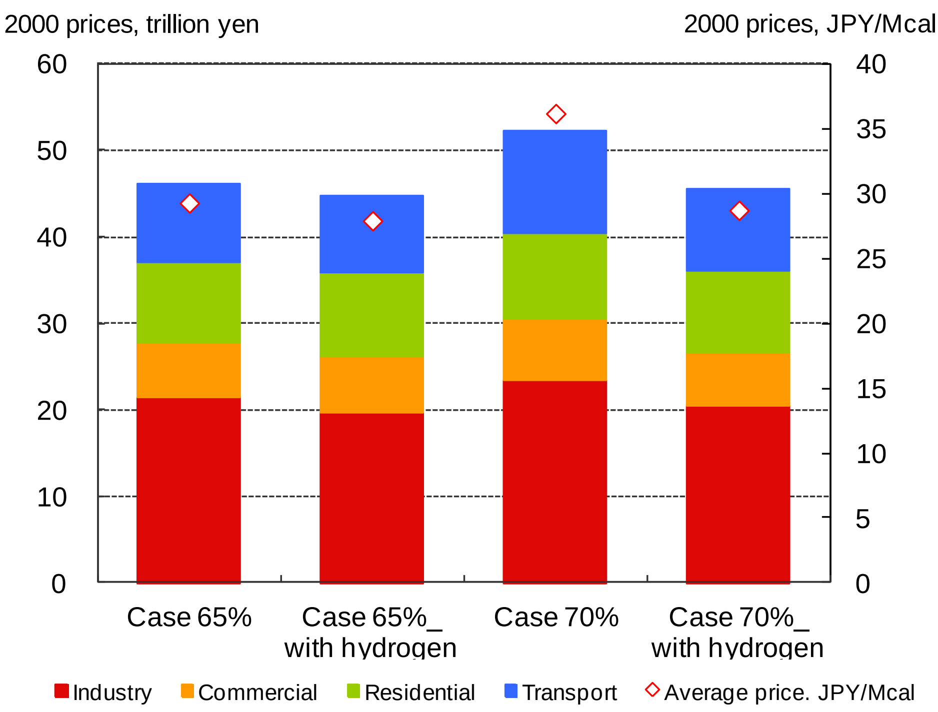

Figure 4-8 Energy costs and average prices at final consumption (2050)

4-6 Primary energy supply

Figure 4-9 shows the primary energy supply in 2050 for the cases where CO_2 constraints are set. The primary energy supply for the cases with hydrogen is 275 Mtoe at the 65% reduction and 255 Mtoe at the 70% reduction, which is an increase of 1.6% and 12.8% respectively in reduction rates compared to the cases without hydrogen. The results indicate that the primary energy supply increases because of expanding economic activity due to the decline in carbon prices.

If we look at the breakdown, for the cases with hydrogen, the CO_2 constraints are mitigated by the use of carbon-free hydrogen, while supplies of coal and oil increase and the supply of natural gas decreases. In addition, 5 Mtoe (19.4 GNm^3) of hydrogen is introduced in the 65% reduction case and 23 Mtoe (89.3 GNm^3) in the 70% reduction case. The results show reduced hydrogen supply compared to the past study[1]. This is because the primary energy supply declines further than for said study, which disregarded the economic feedback due to the diminished economic activity caused by high carbon prices.

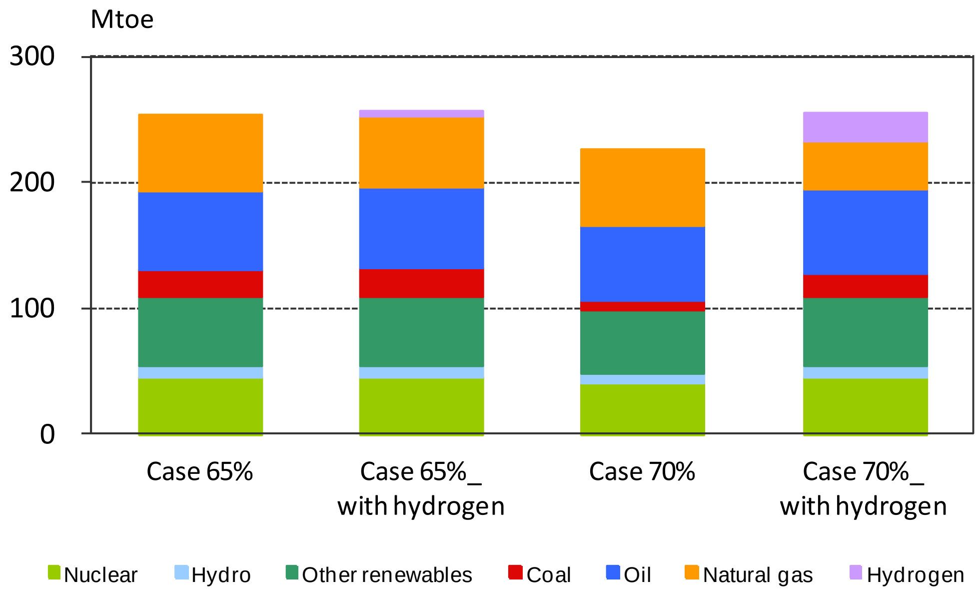

Figure 4-9 Primary energy supply

4-7 Final energy consumption

Figure 4-10 shows final energy consumption in 2050 for all the cases where CO_2 constraints are set. Since economic activity expands with the reduction in carbon price, final energy consumption for the cases with hydrogen increases by 1.8% for the 65% reduction, and by 12% for the 70% reduction compared to cases without hydrogen. It is characteristic of the cases with hydrogen that the consumption of oil and coal increases in the same way as the primary energy supply.

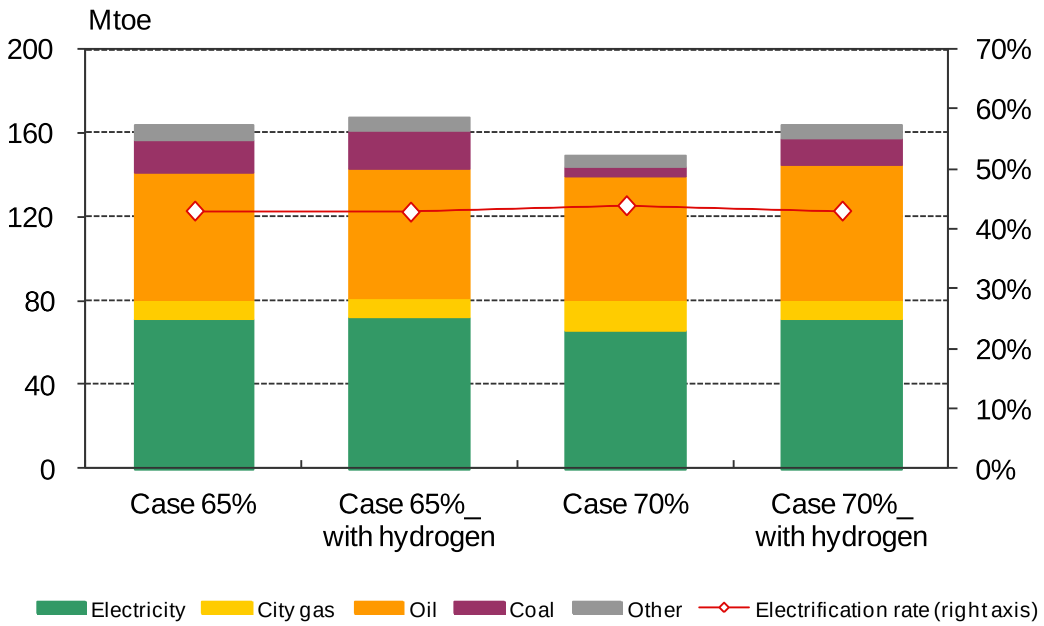

Figure 4-10 Final energy consumption

4-8 Power generation

Figure 4-11 shows the power generation mix in 2050 for the cases where CO_2 constraints are set. For cases with hydrogen, the demand for electricity increases as a result of the decline in carbon prices. For both the Case 65%_with hydrogen and the Case 70%_with hydrogen, electricity generation is 872 TWh, which represents increases of 1.4% and 10% respectively compared to the cases without hydrogen. For cases with hydrogen, natural gas-fired power generation decreases for either reduction rate, and hydrogen-fired power generation is introduced instead. It is 35 TWh in the 65% reduction case and 163 TWh in the 70% reduction case, providing 4.0% and 19% respectively of the total power generation.

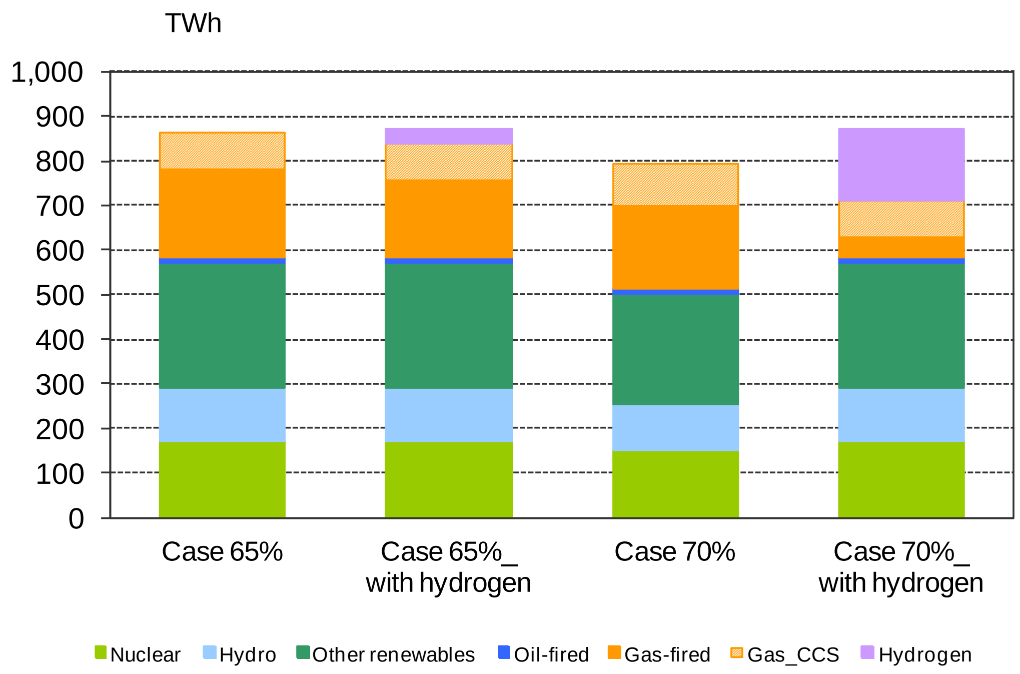

Figure 4-11 Power generation mix

4-9 CO_2 emissions

Figure 4-12 shows energy-related CO_2 emissions in 2050 for each case where CO_2 constraints are set. For either rate of reduction, CO_2 emissions from the power generation sector decrease through the use of hydrogen-fired power generation. In particular, at the 70% reduction, there is a striking decrease in CO_2 emissions from the power generation sector. In the 70% reduction case, CO_2 emissions from the power generation sector decrease, whereas those from the industry increase (up 34% compared to the case without hydrogen). As shown in section 4-1, loss of economic growth is mitigated through the use of hydrogen, but this provides clear indication of the increase in CO_2 emissions due to expanding production activity in the industry.

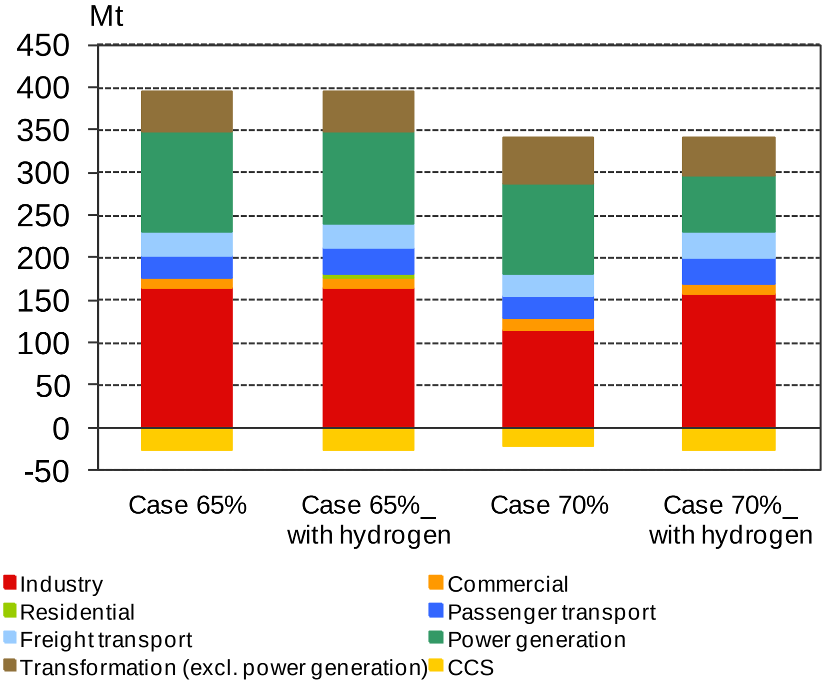

Figure 4-12 Energy-related CO_2 emissions

5. Summary of the Results

Table 5-1 outlines the main energy and economic indicators for each case analyzed for this estimate.

Table 5-1 Main energy and economy indicators (2050)

	Case 0	Case 65%	Case70%	Case 65% with hydrogen	Case 70% with hydrogen
GDP (in 2000 prices, trillion yen)	698	669	637	673	665
Fossil fuels and hydrogen import spending (in 2000 prices, trillion yen)	9.2	8.9	8.4	9.4	10.6
Carbon price (USD/tCO_2 in 2000 prices)	-	423	1,154	340	539
Average energy price (Final consumption, in 2000 prices, JPY/Mcal)	23.0	29.3	36.2	27.9	28.7
Primary energy supply (Mtoe)	306	253	226	257	255
Power generation (TWh)	953	860	791	872	872
Amount of hydrogen introduced (Mtoe)	-	-	-	5	23

6. Conclusion

International climate change negotiations seem to grow increasingly complex as the amount of greenhouse gas emissions rises with the passing years. Emissions reduction targets established under the lead of governments no longer seem to function as guidelines for action due to a lack of feasibility and the severe economic situation in the near term. In actual fact, the results of this study show that overly ambitious reduction targets inhibit growth. Above all, the impact on the economy is considerable for Japan if reduction targets exceed 65% compared to the 1990 level, and if they reach 75%, they are hardly feasible.

In this context, the introduction of hydrogen has the potential to mitigate the negative impact on the economy. As reduction targets become stricter, this is even more obvious in cases where the reductions cannot be met with other relatively inexpensive countermeasures. Carbon-free hydrogen can play an important role as a future energy carrier because it is not extremely expensive, it is possible to roll it out to scale, and it does not have the same instability as renewable energy.

Under present conditions, it is difficult to find the economic rationale for extensive use of hydrogen, but if costs are lowered through technical innovation in the manufacturing, transport and use of carbon-free hydrogen, the situation is likely to change. As other climate change measures progress, or if the focus shifts to other values than the narrowly defined economic ones (for example, dealing with price fluctuations for fossil fuels), it is perfectly possible that the time line until the use of hydrogen is shortened.

The value of hydrogen as a future energy option is positioned correctly when we take the long-term view to 2050 or more. We need to promote coordinated research and development of all supply, transport and demand aspects. Today, when the future of energy policy is without precedent and difficult to predict, we need to consider strategies for the future with a calm eye while always focusing on the uncertainties ahead.

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3) New Energy and Industrial Technology Development Organization (NEDO); International Joint Projects for Development of Clean Coal Technology, Fundamental International Joint Research on Clean Coal Technology, Feasibility Study to Realize a Future Energy System (Hydrogen Supply Chain) Using Carbon-free Fuel Derived from Low Rank Coal (FY2012 - FY2013), Final Report, (2012)
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6) Energy and Environment Council; Innovative Energy and Environment Strategy, September 14, 2012