AN ANALYSIS OF ELECTRICITY SUPPLY COSTS IN JAPAN WITH AN OPTION OF LOW-GRADE COAL UTILIZATION

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Overview

Low-grade coal is getting attention since the prices of other fossil fuels such as oil, natural gas, and high-grade coal are at a high level currently. The purposes of this study are to analyze the effect of introduction of low-grade coal that is at low and stable price levels and to find optimal mix of power generation in Japan considering uncertainty of future prices of fossil fuels. For those purposes, we conduct a research of resource potential of low-grade coal and a time-series analysis of prices of fossil fuels including low-grade coal. Using the fossil data and an optimal power generation mix model, we conduct simulations and obtained the following results. (1) If they transport the low-grade coal with high water content from the production countries to Japan and use the conventional drying process, it has no economic advantage compared with the use of high-grade coal. In order to realize the economic advantage about low-grade coal, they have to reduce the utilization costs such as drying the coal in the production countries and developing innovative drying technologies. (2) The introduction of Low-grade coal decreases the standard deviation of the fuel cost. (3) An LNG intensive case results in not only the largest of the average fuel cost but also the largest variance of the fuel cost.

Introduction

The cost of the power generation section of Japan in the future will be influenced by the prices of fossil fuels, the target of CO2 reduction, and the national energy policy including nuclear power. The price of crude oil is at high at about 100 USD a barrel at the end of November in 2011. The oil price continues to rise, according to the prospects of IEA. The prices of high-grade coal such as bituminous coal have increased. Hence, low price fuels such as low-grade coal are getting attention.

In addition, the reduction of CO2 emissions is an important issue in order to mitigate the damage of long-term global warming. The energy master plan in Japan is in process of readjustment following the nuclear accident led by the East-Japan Earthquake on March 11 in 2011.

The purposes of this study are to analyze the effect of introduction of low-grade coal that is at low and stable price levels and to analyze the optimal-mix of power generatin in Japan considering the uncertainty of future prices of fossil fuels. For those purposes, we conduct a research of resource potential of low-grade coal, a time-series analysis of prices of fossil fuels including low-grade coal, an analysis of future prices of fossil fuels, an analysis of optimal power mixture including low-grade coal in 2020 in Japan, and an analysis of variance of fuel price of power generation in Japan.

Resources of low-grade coal

Before the price analysis of fossil fuels including low-grade coal, we summarize the resources of coal that is classified by the coal type such as bituminous coal/anthracite, sub bituminous coal, and lignite 1)2). According to WEC, the expected resource potential (reserves, resources, and expected resources) of coal in the world is at 10.6 trillion tonnes estimated in 1990, at 3.4 trillion tonnes estimated in 2002, and 2.8 trillion tonnes estimated in 2005. Since the latest data in 2005 include many deficit values, we use the data in 2002 and summarize the regional resources and the resources by coal-type (Figure 1). We define that high-grade coal consists of bituminous and anthracite and low-grade coal consists of sub bituminous coal and lignite. The ratio of high-grade coal to low-grade coal is 48 to 52 by bulk weight and 61 to 39 by heat value. Low-grade coal resources are not only large volume but also widely distributed over the world (Figure 1).

Time-series analysis of fossil fuel prices

Using the time-series data of fossil fuels including low-grade coal based on the data of EIA in the United States 3), we conduct a time-series analysis of the prices of the fossil fuels. Figure 2 shows the transition of the prices per giga joule of the fossils in the United States from 1949 to 2009. The prices are the real prices in 2005 and the heat values are based on IEA statistics 4).

Using the the data in Figure 2, we calculate the average and the variance of the prices of the fossils (Table 1 and Figure 3). The table and the figure show the prices of low-grade coal have lower variance compared to those of other fuels such as oil, natural gas, and high-grade coal. In addition, we conduct Kolmogorov-Smirnov Test and confirm normal distribution of the residual errors that are the prices minus the drift values. Table 2 and 3 show that all the correlation coefficients among low-grade coal, high-grade coal, oil, and natural gas exceed 0.4 and we confirm these coefficients are significant by conducting F-test.

We assume that the difference between the prices in the United States (Table 2) and CIF prices in Japan based on EDMC database is equivalent to transportation cost (including insurance cost) concerning high-grade coal, oil, and natural gas. Since Japan does not import low-grade coal commercially, there is no CIF price data of low-grade coal. Thus, we assume that the transportation cost of low-grade cost is equal to that of high-grade coal on the basis of coal weight. The heat value of low-grade coal is about half as much as that of high-grade coal; hence, the transportation cost per joule of low-grade coal is about twice as much as that of high-grade coal. The HHVs of low-grade coal and high-grade coal are 14.5 GJ/kg and 28.0 GJ/kg, respectively.

The prices of fossils of oil, natural gas, high-grade coal, and low-grade coal in the United States in 2009 are 8.6, 4.3, 1.8, and 1.1 USD/GJ, respectively. We assume the transportation costs of those are 0.5, 2.6, 0.9, 1.7 USD/GJ, respectively. The assumed CIF price of low-grade coal at 2.8 USD/GJ is more expensive than the CIF price of high-grade coal at 2.7 USD/GJ. Since we assume that "crude" low-grade coal with high water content is transported, low-grade coal need high transportation costs per joule. Thus, the CIF cost of low-grade coal is more expensive than that of high-grade cost.

We assume the future exchange rate is constant at 110 JPY per USD, although the rate affects seriously the fuel cost in JPY.

Scenarios of fossil fuel prices

Using the data in the previous section and the assumption of IEA/WEO 8), we build a simplified scenarios of fossil fuel prices in 2020 considering the variance and covariance of the prices of fossil fuels.

The basic concept of the scenario building is as follows. (a) The future prices of fossil fuels consist of the average prices and the residual errors. (b) The average price of crude oil will be exogenous following New Policy Scenario of IEA/WEO 8). (c) The average prices of the other fossil fuels in the future will be calculated using the future oil price and the correlation functions based on the past data (Table 3). (d) The residual errors of fossil fuels in the future will keep the variance and covariance of the residual errors based on the past data (Table 2 and 3).

Table 4 shows the estimated average prices of fossil fuels in 2020.

The residual errors of fossil fuels in the future are calculated as follows. We assume the residual errors of each fossil fuel are in normal distribution (that was confirmed in the previous section). We sample ten data at equal intervals of 10% on the cumulative probability function of the residual errors. The 10 data are at 5%, 15%, 25%, ..., 95% on the cumulative probability function. Then, we select the top 100 combination of the sampling data, the covariance of which is close to the covariance based on the past data (Table 2 and 3). Each combination we selected includes 10 pairs of the sampling data and the total pairs are 1000 pairs of the residual errors.

Optimal power supply model with low-grade coal

We modify an optimal power supply model of Japan that is one region model 6) in order to evaluate not only high-grade coal power but also low-grade coal power (Figure 4).

We assume that the low-grade coal with about 45% of water-content is converted to the dried coal with about 15% of water-content in a drying process and that the dried coal is fueled at coal power plants. A conventional and commercial method that is a convection heat-transfer drying is adopted in the optimal power model, although innovative drying methods such as self-heat reproduction drying and dimethyl-ether drying are proposed 7).

Table 5 shows input data specifications of optimal power mixture model including the efficiency and the cost of the drying process. In this model, we assume that low-grade coal with high-water content are transported from production countries to Japan and it are dried and fuelled at power plants in Japan. We assume the following four simulation cases in 2020.

B-1.0-t case: All power plants on the list of an electric power development plan that are under-construction and under-contemplation 5) will be introduced according the plan. The electric power development plan in Japan published in 2011 does not consider the effect of East Japan Earthquake occurred on March 11 in 2011. The additional power sources that are not included on the power development list and the operation of power sources in 2020 are calculated by the optimal power mix model.

Nu-1.0-t case: This is an extreme case where nuclear sources generate no electricity in 2020. All the assumptions except nuclear sources are the same as those in B-1.0-t. The additional power sources and the operation of power sources in 2020 are calculated by the optimal power mix model.

Nu-0.8-t case: We assume the transportation cost of low-grade coal will decrease by developing a new transportation system such as dried coal transportation and the CIF price of low-grade coal is 0.8 times as much as the CIF price in B-1.0-t case. In B-1.0-t case, the transportation cost occupies about half of the CIF price and the reduction of the transportation cost is a key issue to use low-grade coal in Japan. All the assumptions except the cost of low-grade coal are the same as those in Nu-1.0-t.

Nu-lng-t case: This case is an LNG power intensive case because an LNG is considered as a possible candidate to supply additional power in the short term in Japan. The assumptions except LNG are the same as those in Nu-1.0-t. In Nu-lng-t case, we assume the additional power sources that are not included on the power development list are restricted to only LNG power sources. The operation of power sources in 2020 are calculated by the optimal power mix model.

In all the cases, we do not consider CO2 discharge costs.

Calculation results using an optimal power mix model

Based on the cases defined in the previous section, we conducted simulations of the power generation in Japan in 2020 using the optimal power mix model including low-grade coal. Figure 5 shows the annual power generation in units of watt-hour, Figure 6 shows the power capacity in units of watt, Figure 7 shows the capital amortization cost of power generatin facilities, and Figure 8 shows the annual fuel costs including nuclear fuel costs.

In Nu-1.0-t case, high-grade coal power will be dominant because high-grade coal is less expensive than other fuels such as oil, natural gas, and low-grade coal with the drying process. If they transport the low-grade coal with high water content from the production countries to Japan and use the conventional drying process, it has no economic advantage compared with the use of high-grade coal.

Low-grade coal will be utilized in only Nu-0.8-t case where we assumed the cost reduction of the transportation of low-grade coal. In order to realize the economic advantage about low-grade coal, they have to reduce the utilization costs by new systems such as drying the coal in the production countries and developing innovative drying technologies.

In B-1.0-t case, the capital amortization cost and the fuel cost are relatively small, and the total cost is the smallest in the all cases.

In Nu-lng-t case, the capital amortization is the smallest but the fuel cost is about twice or more as much as those in the other cases. The total cost in Nu-lng-t case is the highest in the all case.

In the two coal intensive cases of Nu-1.0-t and Nu-0.8-t, the capital amortization costs and the fuel cost are sub equal each other. In those cases, the capital amortization costs are high and the fuel costs and the total costs are intermediate in the all cases.

The CO2 emissions in the four cases are at 81.04 million tonnes-C in B-1.0-t case, at 190.83 million tonnes-C in Nu-1.0-t case, at 206.98 million tonnes-C in Nu-0.8-t case, and at 122.03 million tonnes-C in Nu-lng-t case. The CO2 emissions in coal dominant cases such as Nu-1.0-t case and N-0.8-t case are more than twice as much as that in B-1.0-t.

Hence, the coal-intensive cases of Nu-1.0-t and Nu-0.8-t have a defect about the CO2 emissions and the LNG-intensive case of Nu-1ng-t has a defect about the fuel cost.

Analysis of future fuel costs considering variance and covariance

We analyze the fuel costs of the four cases (see the previous section) considering the variance and covariance of the costs of fossil fuels based on the past data (see the second section).

In the analysis, we assume the fuel cost of nuclear is constant and no variance (Table 5), since the fuel cost of nuclear depends mainly on the refinement cost.

Table 6 shows the fuel costs with variance, Figure 9 shows the fuel costs in the form of cumulative probability density distribution, and Figure 10 shows the fuel costs in the form of probability density distribution.

B-1.0-t case that is based on the plan of the electric power development in 2010 results in not only the smallest of the average fuel cost but also the smallest variance. The standard deviation of the fuel cost in B-1.0-t case is about half as much as that in B-1.0-t case, and about one-third as much as that in B-lng-t case (Figure 10).

On the other hand, Nu-lng-t case that is an LNG intensive case results in not only the largest of the average fuel cost but also the largest variance of the fuel cost (Figure 10).

Nu-0.8-t case with introduction of low-grade coal decreases by only 1% the average fuel cost but decreases by about 20% the standard deviation of the fuel cost compared to the results in Nu-1.0-t case without introduction of low-grade coal (Table 6 and Figure 10). The result suggests the introduction of low-grade coal decreases the accent risk of fuel cost. When we assume more introduction of low-grade coal, it may cause the additional decrease of the variance of the fuel cost in Japan.

For an example of a high fuel cost, the fuel costs at 99% of the cumulative probability density are 2.81, 4.06, 3.85, 6.80 trillion JPY in B-1.0-t, Nu-1.0-t, Nu-0.8-t, Nu-lng-t, respectively. Then, Nu-lng-t case needs by about 4 trillion JPY more fuel cost than B-1.0-t case needs.

Conclusions

The cost of the power generation section of Japan in the future will be influenced by the prices of fossil fuels, the target of CO2 reduction, and the national energy policy including nuclear power. Low-grade coal is getting attention since the prices of the other fossil fuels such as oil, natural gas, and high-grade coal are at a high level currently.

The purposes of this study are to analyze the effect of introduction of low-grade coal that is at low and stable price level and to find an optimal mix of power generation in Japan considering uncertainty of future prices of fossil fuels. For those purposes, we conduct a research of resource potential of low-grade coal and a time-series analysis of prices of fossil fuels including low-grade coal. Using the fossil data and an optimal power generation mix model, we conduct simulations and obtained the following results. (1) If they transport the low-grade coal with high water content from the production countries to Japan and use the conventional drying process, it has no economic advantage compared with the use of high-grade coal. In order to realize the economic advantage about low-grade coal, they have to reduce the utilization costs such as drying the coal in the production countries and developing innovative drying technologies. (2) The introduction of Low-grade coal decreases the standard deviation of the fuel cost. (3) An LNG intensive case results in not only the largest fuel cost but also the largest variance of the fuel cost.

We plan to evaluate innovative drying processes, cost reduction of transportation by drying low-grade coal in coal production countries, and the effect of costs and CO2 emissions by introducing renewable power sources such as photovoltaic and wind.

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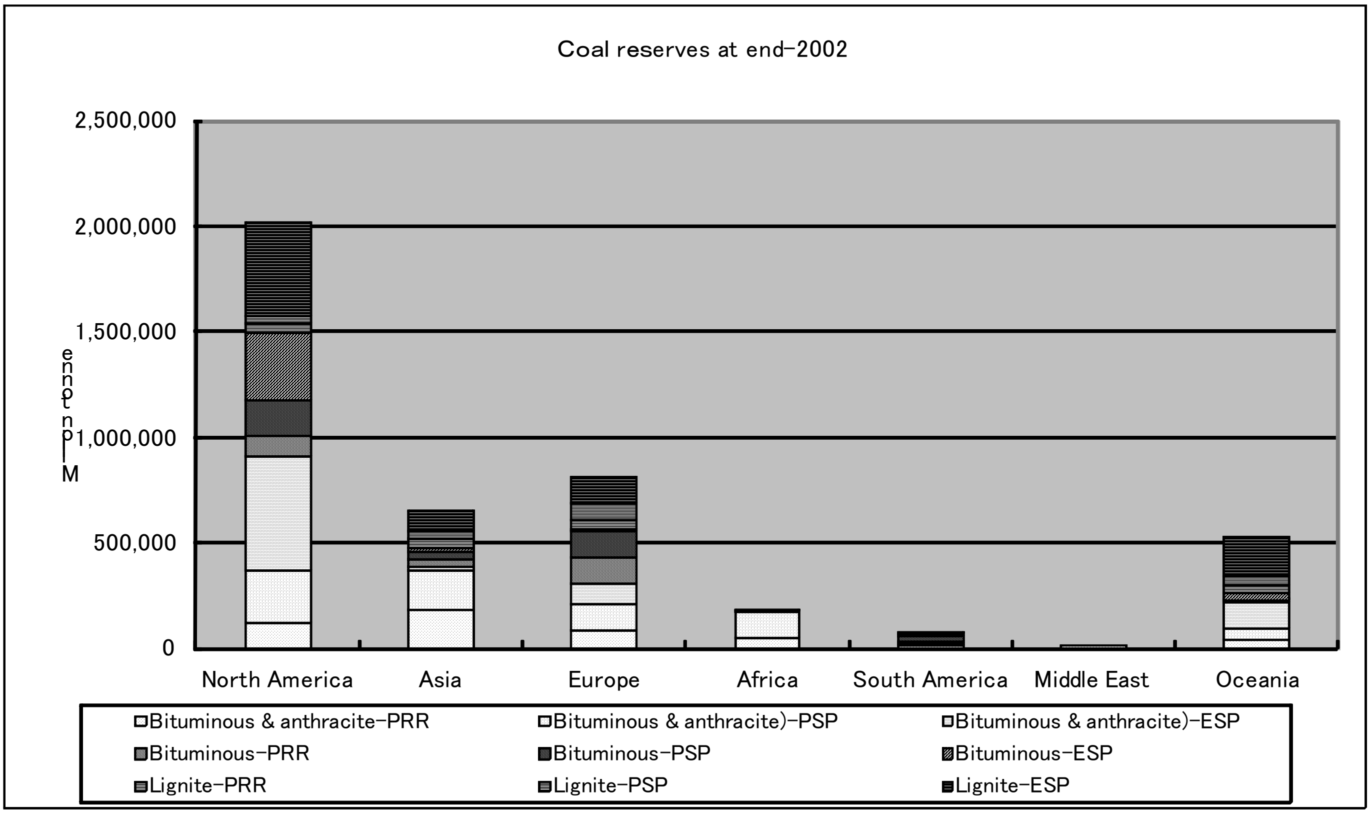

Figure 1 Expected reserves on the weight basis

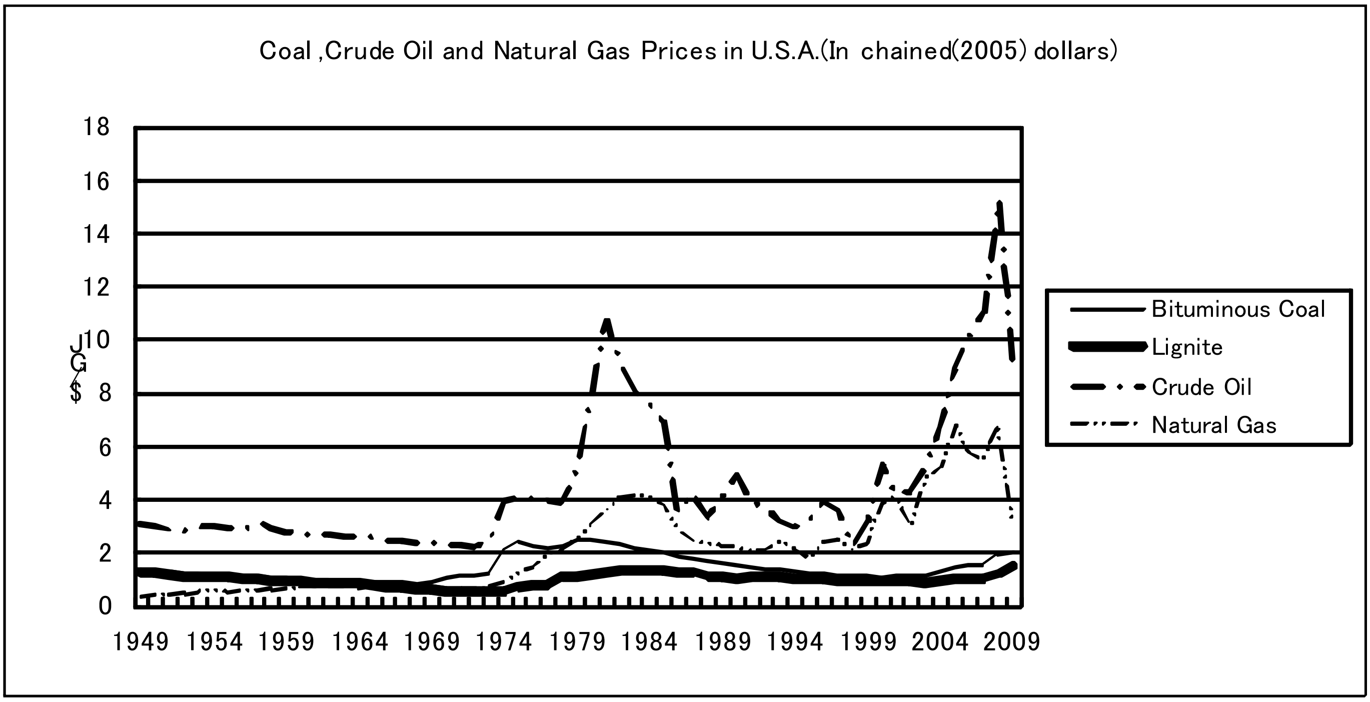

Figure 2 Transition of prices of fossil fuels in the United States (in 2005 USD)

Table 1 Average and variance of prices of fossil fuels in the United States (since 1949 and in 2005 USD)

Item \ Fuel	Coal: Bituminous	Coal: Lignite	Crude Oil	Natural Gas
Number of Sample	61	31	61	61
Average Prices	57.05	13.59	25.33	2.29
	2.30	0.75	4.45	2.11
Minimum Prices	38.60	7.36	12.71	0.41
	1.56	0.41	2.24	0.38
Maximum Prices	96.12	24.13	86.69	7.34
	3.88	1.34	15.24	6.77
Variance	291.45	31.50	236.19	3.32
	0.48	0.10	7.30	2.83
Standard deviation	17.07	5.61	15.37	1.82
	0.69	0.31	2.70	1.68

Notes:
Upper values are in original unit such as USD/Short ton (Coal), USD/bbl(Crude Oil), and USD/kft^3(Natural Gas).
Lower values are in USD/GJ (HHV). USD means USD in 2000.

Table 2 Correlation coefficient of prices of fossil fuels in the United States (since 1949 and in 2005 USD)

x \ y	Coal: Bituminous	Coal: Lignite	Natural Gas	Crude Oil
Coal: Bituminous	1.000			
Coal: Lignite	0.447	1.000		
Natural Gas	0.415	0.405	1.000	
Crude Oil	0.571	0.486	0.848	1.000

Correlation coefficient above 0.7

Correlationcoefficient between 0.4 and 0.7

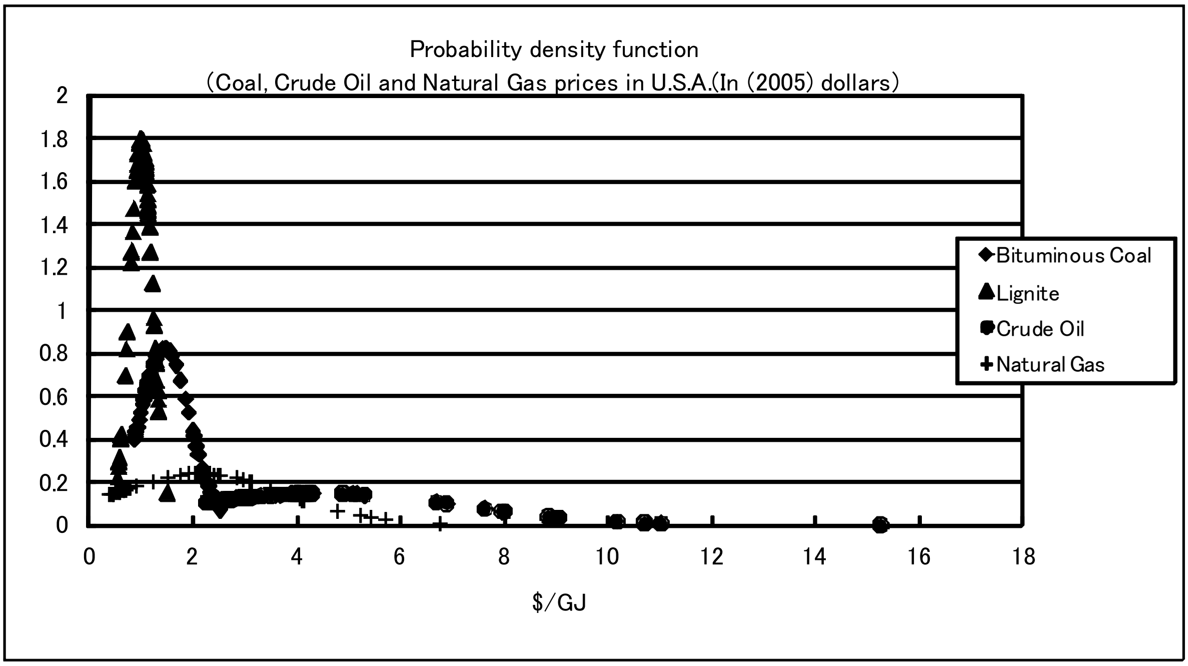

Figure 3 Probability density of prices of fossil fuels

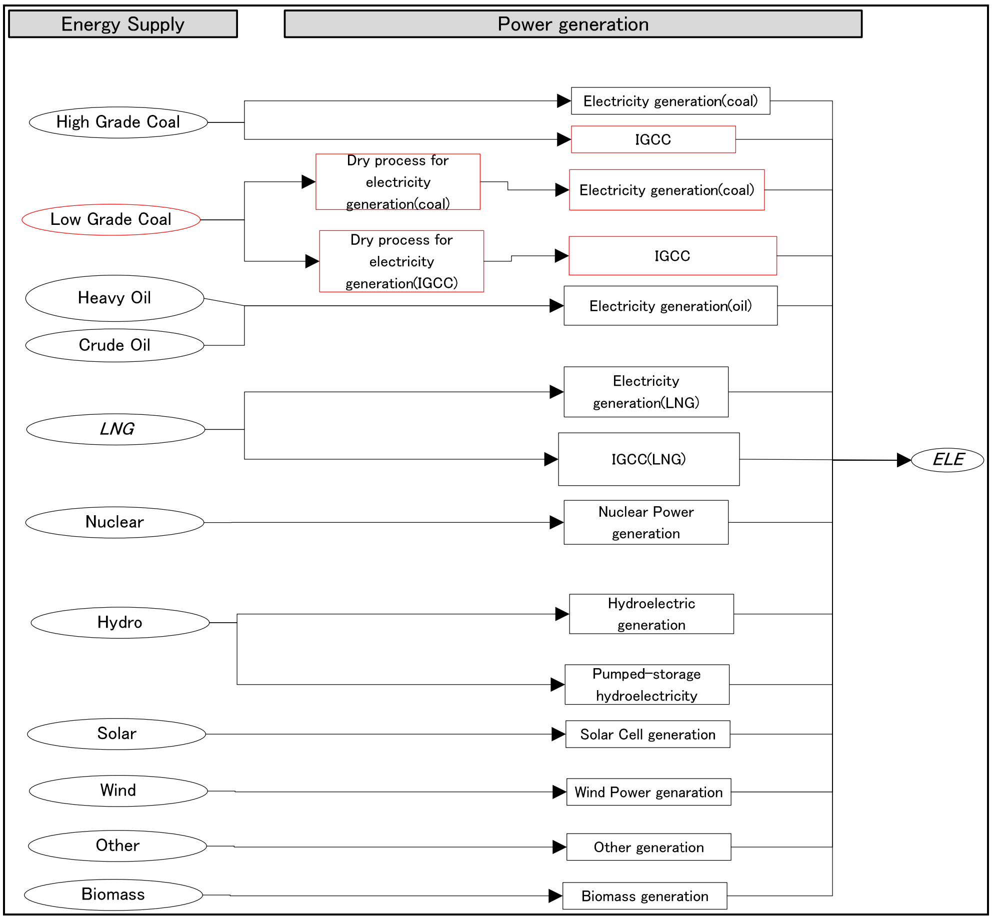

Figure 4 Optimal power mix model including low-grade coal

Table 3 Correlation function of prices of natural gas, high-grade coal (bituminous), and low-grade coal (lignite) against crude oil

	y		
	Natural Gas	Bituminous	Lignite
Slope(a)	0.528	0.102	0.040
Intercept(b)	−0.212	0.881	0.727
Correlation coefficient	0.848	0.571	0.486
Coefficient of determination	0.719	0.326	0.236

Table 4 Estimated average prices of fossil fuels in the future (CIF prices)

				New Policies Scenario				
			2009	2015	2020	2025	2030	2035
Crude Oil	JPY (2000)	yen/kl	36,349	53,099	57,901	61,251	64,042	65,717
Natural Gas	JPY (2000)	yen/t	38,424	49,556	52,747	54,974	56,829	57,943
Bituminous	JPY (2000)	yen/t	8,148	9,457	9,833	10,095	10,313	10,444
Lignite	JPY (2000)	yen/t	4,571	4,841	4,919	4,973	5,018	5,045

Table 5 Input data specifications of optimal power mixture model.

		Unit	Low-grade coal (with a drying process of convection heat-transfer) (45.6% of moisture content before dry)	High-grade coal	LNG	LNG-CC	Oil
Efficiency	Drying process efficiency	-	0.8314	-	-	-	-
	Power generation efficiency	-	0.4215	0.4215	0.396	0.465	0.394
	Transmission-end efficiency	-	0.93	0.93	0.955	0.97	0.95
	Total efficiency (at generation end)	-	**0.3504**	**0.4215**	**0.3960**	**0.4650**	**0.3940**
	Total efficiency (at transmission end)	-	**0.3259**	**0.3920**	**0.3782**	**0.4511**	**0.3743**
Plant cost	**Cost proportional to kW**		Capacity of new facilities **K**[kW] * Construction unit price **UC**[10000JPY/kW] * { Annual expense rate of the co rate of O&M cost **OMKW**[%] }				
	Construction cost (UC)	10,000 yen/kW	27.2+1.6=28.8	27.2	16.4	16.4	26.9
	Durable year	year	40	40	40	40	40
	Annual expense rate of capital cost (DEP1)	%	4.95	4.95	4.95	4.95	4.95
	Annual expense rate of O&M cost	%	0	0	0	0	0
	Cost proportional to kWh		Power generation **POW**[kWh] * Annual expense rate of O&M cost **OMKWH**[yen/kWh]				
	Annual expense rate of O&M cost (OMKWH)	yen/kWh	1.5+0.09=1.59	1.5	1.1	1.1	1.5
Fuel	Heating value(HHV)	kcal/kg kcal/L	3,456	6,687	13,019	13,019	9,126
	Moisture content before drying	%	45.6	—	—	—	—
	Price(CIF)(2020)	yen/t,kL,kWh	4,919	9,833	52,747	52,747	57,901
	Price per HHV	yen/Mcal	1.42332	1.47047	4.05154	4.05154	6.34462
	Price Ratio	-	0.96794	1.00000	2.75528	2.75528	4.31470

Notes: 1) The plant costs are based on the ninth Agency for Natural Resource and Energy Comprehensive Energy Committee, cost examination subcommittee, document No. 4 of "cost comparison (2004) of each power gener

2) The price that nuclear fuel is based on the ninth Agency for Natural Resource and Energy Comprehensive Energy Committee, cost examination subcommittee, document No. 4 of "cost comparison (2004) of each power supp

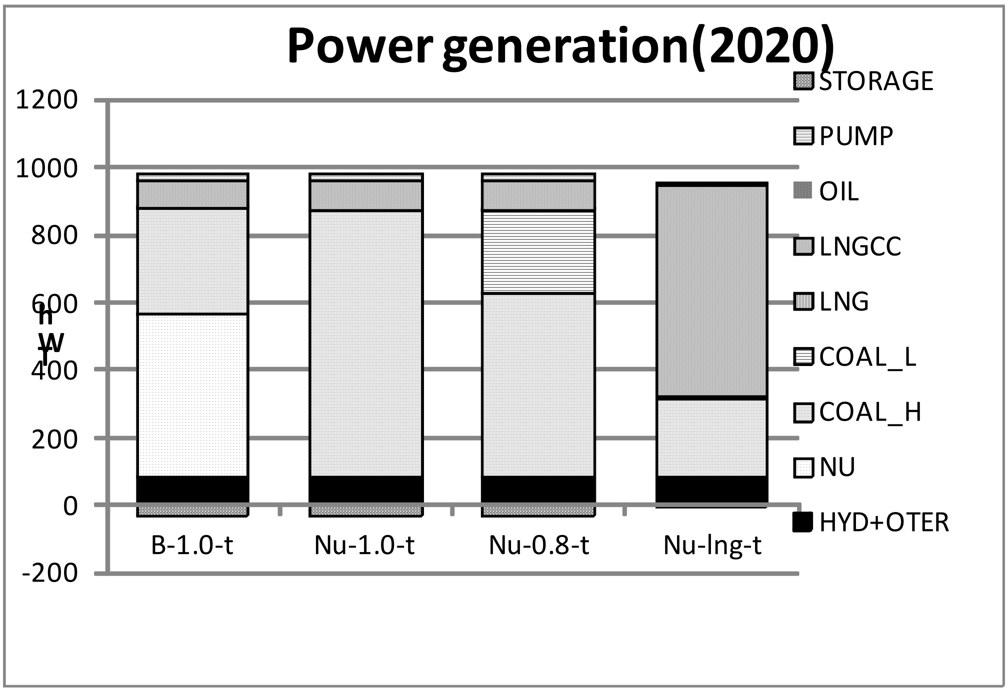

Figure 5 Electric energy of power generation in 2020

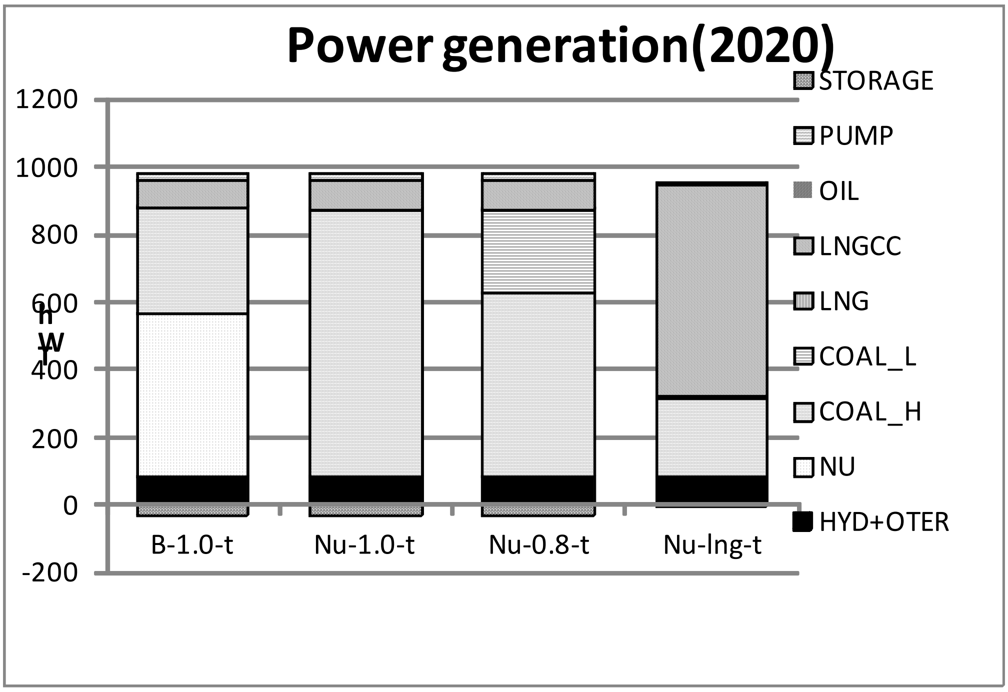

Figure 6 Capacities of power generation in 2020

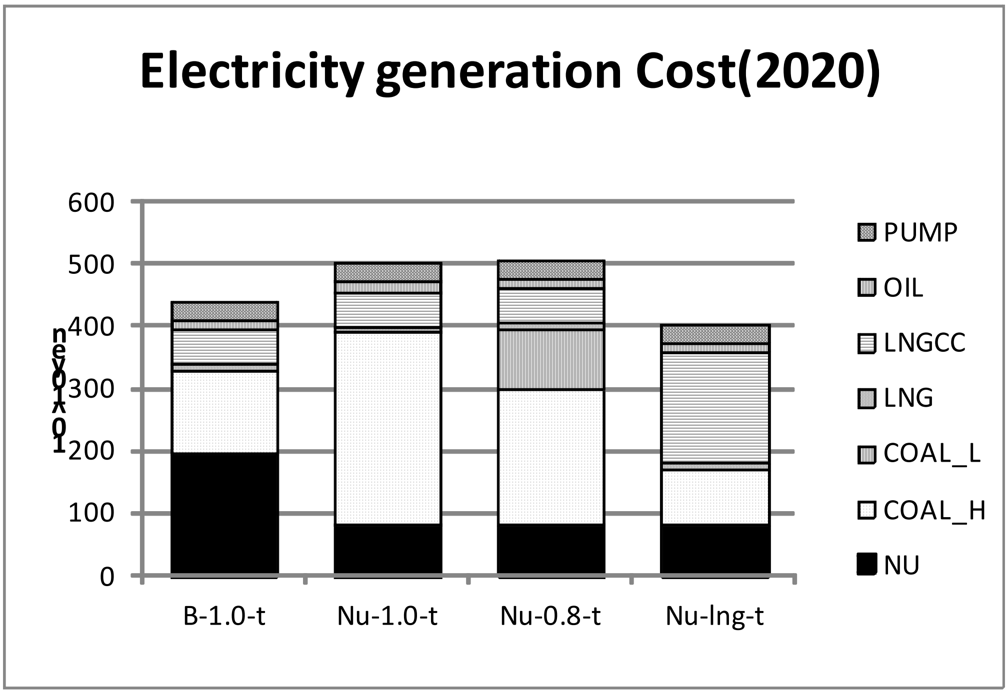

Figure 7 Annual amortization costs of power generation facilities in 2020

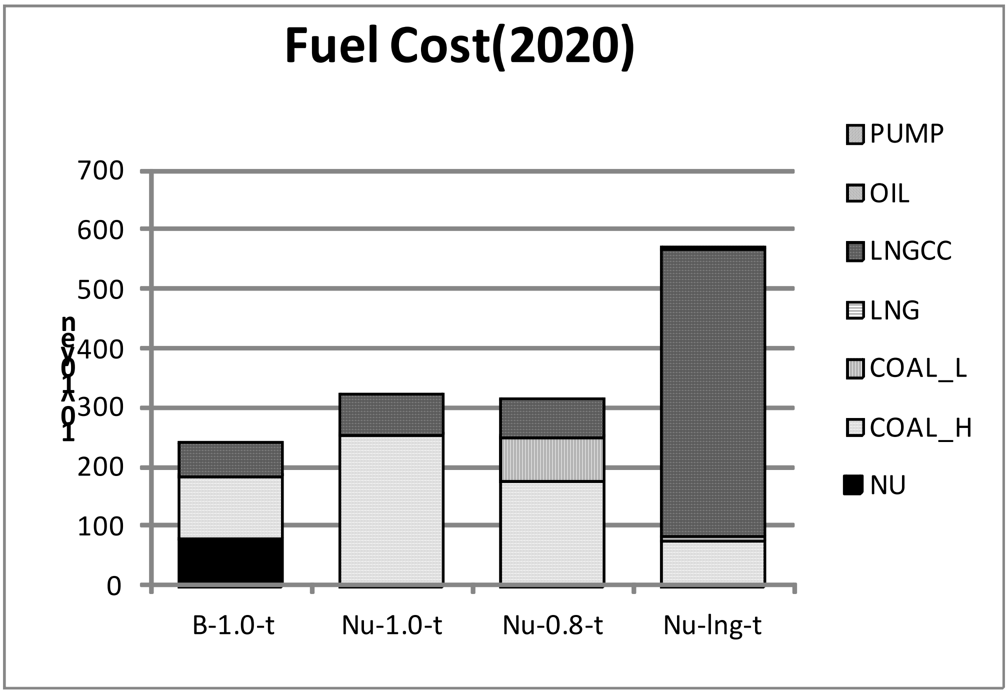

Figure 8 Fuel costs in 2020

Table 6 Fuel costs with variance in 2020

				10 billion yen
	B-1.0-t	Nu-1.0-t	Nu-0.8-t	Nu-lng-t
Average	241.7	321.7	316.0	565.7
Maximum	271.8	384.9	372.2	652.0
Minimum	211.6	258.4	259.7	479.4
Variance	284.9	1,315.1	873.1	2,421.0
Standard deviation(Sigma)	16.9	36.3	29.5	49.2
90%	263.3	368.1	353.9	628.7
95%	269.5	381.3	364.6	646.6
99%	281.0	406.0	384.7	680.1
10%	220.1	275.2	278.1	502.6
5%	213.9	262.0	267.4	484.7
1%	202.4	237.3	247.2	451.2
Average+Sigma	258.6	357.9	345.5	614.9
Average+Sigma*2	275.5	394.2	375.1	664.1
Average+Sigma*3	292.3	430.5	404.6	713.3
Average-Sigma	224.8	285.4	286.4	516.5
Average-Sigma*2	207.9	249.1	256.9	467.3
Average-Sigma*3	191.1	212.9	227.3	418.1

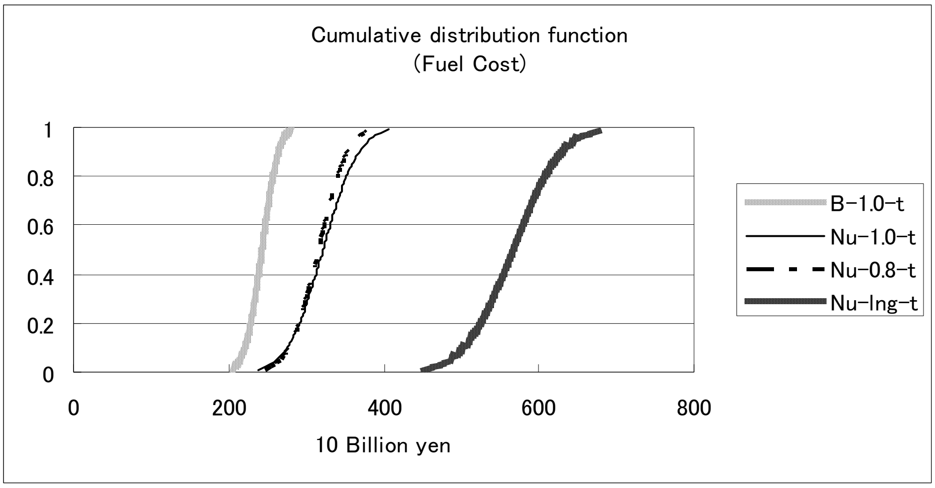

Figure 9 Cumulative probability density distribution of fuel costs in 2020.

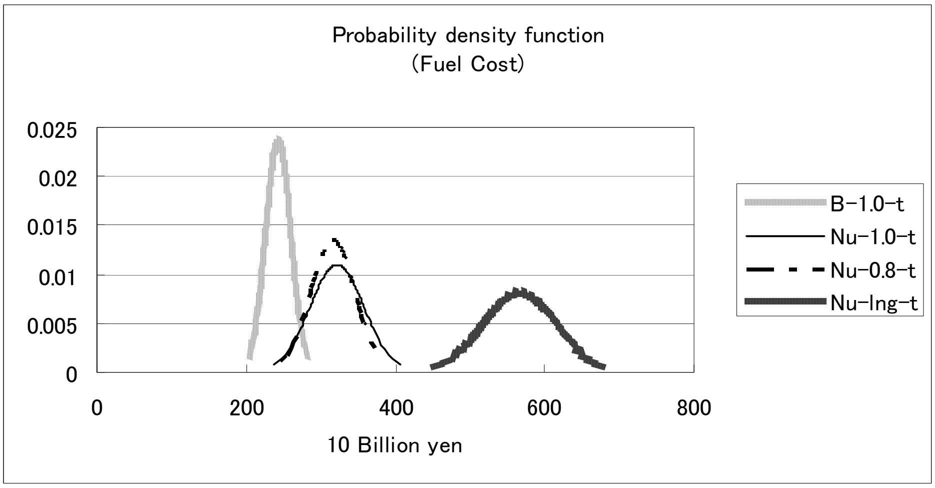

Figure 10 Probability density of fuel costs in 2020