Thermal and Nuclear Power Generation Cost Estimates
Using Corporate Financial Statements

Yuhji Matsuo,[1] Yu Nagatomi[2] and Tomoko Murakami[3]

Summary

There are two generally accepted methods for estimating power generation costs: so-called "model plant" method and the method using corporate financial statements. The method using corporate financial statements, though under some constraints, can provide useful information for comparing thermal and nuclear power generation costs. This study used this method for estimating thermal and nuclear power generation costs in Japan for the past five years, finding that the nuclear power generation cost remained stable at around 7 yen per kilowatt-hour (kWh) while the thermal power generation cost moved within a wide range of 9 to 12 yen/kWh in line with wild fluctuations in primary energy prices.

The cost of nuclear power generation is expected to increase due to the enhancement of safety measures and accident damage compensation in the future, while there are reactor decommissioning, backend and many other costs that the financial statement-using approach cannot accurately estimate. In the future, efforts should be continued to comprehensively and accurately estimate total costs.

1.   Introduction

The Fukushima Daiichi nuclear plant accident triggered by the Great East Japan Earthquake has led to serious developments of massive radiation leaks and residents' long-term evacuation, exerting great impacts on nuclear energy policies in Japan and other countries. The Strategic Energy Plan[1)] calls for building nine new commercial nuclear reactors by 2020, and 5 more by 2030. In response to the accident, however, the Prime Minister instructed that the plan be reformed. Japan's nuclear energy policy may have to be dramatically reformed. Irrespective of the Fukushima nuclear plant accident, however, Japan will remain required internationally to reduce greenhouse gas emissions. In resources-poor Japan, nuclear energy viewed as a quasi-domestic energy resource will remain important for stable energy supply. How nuclear energy would be positioned under such situation is still uncertain.

Power generation costs are important for considering the use of nuclear energy. Nuclear power generation has been promoted in many countries as a power generation method that emits no carbon dioxide and allows massive electricity to be generated cheaply. Even at present after the Fukushima Daiichi nuclear plant accident, nuclear energy development leaders such as the United States, France and Russia, and emerging countries like China and India have not changed their basic nuclear energy promotion policies. It may be needless to note that safety and nuclear nonproliferation are the most important preconditions for the use of nuclear energy. Apart from these problems, however, the estimation of nuclear power generation costs should be very important for assessing future nuclear policies in Japan and the world.

In Japan, the Subcommittee to Study Costs and Other Issues in the government's Advisory Committee for Natural Resources and Energy released hydro, thermal and nuclear power generation cost estimation results[2)] in 2004. Given a service life of 40 years, a capacity factor of 80% for thermal and nuclear and 45% for hydro power plants, and a discount rate of 3%, the unit cost was estimated at 11.9 yen/kWh for conventional hydro power generation, 10.7 yen/kWh for oil thermal generation, 6.2 yen/kWh for LNG thermal generation, 5.7 yen/kWh for coal thermal generation and 5.3 yen/kWh for nuclear generation. Nuclear energy was thus viewed as a lower-cost electricity source.

Meanwhile, U.S. estimates frequently indicate that the unit cost for nuclear power generation is higher than for thermal power generation[3)4)5)6)]. This is mainly because a discount rate viewed as appropriate in Japan is lower than those in the

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[1] Senior Researcher, Nuclear Energy Group, the Institute of Energy Economics, Japan
[2] Researcher, Energy Data and Modelling Center, the Institute of Energy Economics, Japan
[3] Group Manager, Nuclear Energy Group, the Institute of Energy Economics, Japan

United States[7]. As well as such difference, however, we may have to consider nuclear plant construction costs that have risen on various factors including building material and equipment price hikes[4][5]. Therefore, our urgent challenge is to estimate costs for various power generation methods as accurately as possible based on up-to-date data.

The "model plant" approach and the method using corporate financial statements are widely used for estimating power generation costs. The former approach sets the unit construction cost, fuel cost, operation and maintenance cost and other costs for a power generating plant and estimates the unit generation cost based on a certain discount rate and revenue/outlay balance for long-term plant operation. The financial statement-using approach estimates actual power generation costs based on data as specified in electric utilities' financial statements[8]. This study, building on past studies, attempted to use the latter approach for estimating thermal and nuclear power generation costs.

2.   Calculation methods

2-1   Kunitake et al. (1999)

Kunitake et al. used corporate financial statements of nine Japanese electric power utility companies to compute nuclear power generation costs and their breakdown based on actual data and estimated the future outlook of the costs[9][10]. Their approach is as follows:

They computed unit power generation costs by dividing a fiscal year's hydro, thermal and nuclear power generation costs by power output. Power generation costs here cover electric utility operating expenses and interest payments in profit-and-loss statements. While electric utility operating expenses are broken down for hydro, thermal and nuclear power generation in profit-and-loss statements, interest payments are not. Kunitake estimated interest payments for each power generation method by allocating interest payments for overall electric utility operations to each power generation method based on the share of electric utility fixed assets and construction in progress account.

Kunitake used gross output specified in financial statements as the denominator of the division to compute unit costs. Generally, net output is several percent less than gross output due to power plants' in-house electricity consumption. If net output is used for the division to compute unit costs, any unit cost may be higher than for a case where gross output is used.

Furthermore, Kunitake used detailed lists of electric utility operating expenses to classify power generation expenses into three categories – capital, operation and maintenance, and fuel cycle costs – based on which unit power generation costs were broken down. The capital cost here covers the above-mentioned interest payments as well as such expenses as fixed asset tax and amortization expenses, indicating the cost for power generation equipment construction and the like. It also covers the cost for dismantling nuclear power facilities. Operation and maintenance expenses include such personnel expenses as wages and benefits, repair costs and supplies expenses. Fuel cycle costs cover spent fuel reprocessing costs as well as fuel expenses (fossil and nuclear fuels).

The results of this estimation in Figure 2-1 indicate that the unit cost for thermal power generation rose substantially in 1974 and 1980 after the respective oil crises and fell to almost the same as nuclear or hydro power generation cost levels in line with crude oil price drops. Meanwhile, the unit nuclear power generation cost fluctuated widely in the first half of the 1970s just after Japan's introduction of nuclear power generation. It later remained relatively stable. Rather, it has indicated a modest downward trend since the 1980s. Various factors behind the downward trend are conceivable. Cited as a major factor is an interest payment fall indicated by a drop of the long-term lending rate for electric power utilities from more than 8% in 1971 to around 3% in 1996. In fact, interest payments' share of the unit nuclear power generation cost has been large and dropped persistently from the 1970s to 1996, as shown in Figure 2-1. Anyway, a major characteristic point of nuclear power generation is that the capital cost accounted for about half of the total unit cost even in 1996.
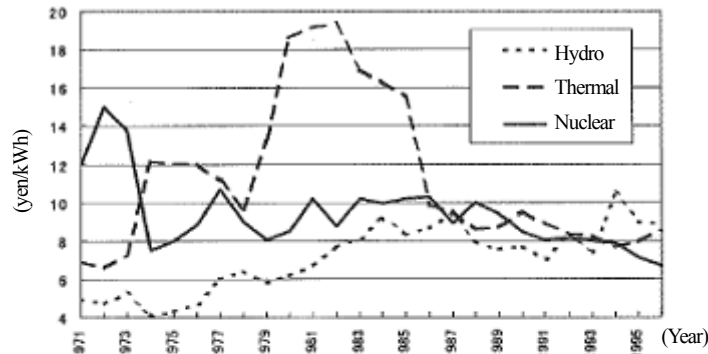
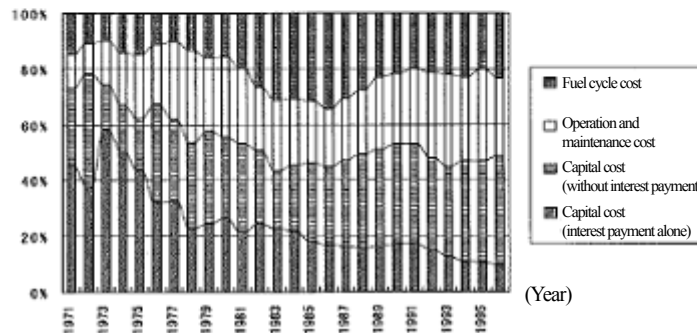**Figure 1 Power Generation Costs Calculated form Financial Statements**

Figure 2 Composition of Nuclear Power Generation Cost

Figure 2-1 Hydro, Thermal and Nuclear Power Generation Costs Estimated from Financial Statements (Kunitake, 1999)

2-2 Oshima (2010) , etc.

Oshima improved the Murota[11)12)] approach to use corporate financial statements of nine electric power utility companies to estimate power generation costs[13)].

Murota's approach calculates power generation costs according to the rules for calculation of charges under electricity supply contracts. The costs consist of the operating expenses and business return. The former is the same as the above electric utility operating expenses. The latter is calculated by multiplying the rate base including fixed electric utility assets by rate of return. Murota's approach differs from Kunitake's approach in that it covers the rate of return instead of interest payments adopted for Kunitake's approach.

In response to Murota's approach, Oshima made new estimates for the FY1970-2007 period, newly considering the following points:

(1) Treatment of pumping-up hydro power generation

Murota's approach[12)] divided hydro power generation into conventional hydro generation and pumped hydro generation and added the unit cost for pumped hydro power generation to that of nuclear power generation. Oshima fine-tuned Murota's approach, dividing pumped hydro generation into natural flow generation and pumping-up generation and adding only the latter to nuclear power generation.

(2) Treatment of development and siting costs

Oshima named costs for technology development and management of relevant organizations for electricity sources as "development costs" and costs for siting power stations as "siting costs." Development costs divided by power output are called "the unit development cost" and siting costs divided by power output are named "the unit siting cost." Specifically, Oshima classified expenses for the relevant energy sources (hydro, thermal and nuclear) in the National Special Account for

Electric Power Development Promotion and the General Account (science & technology promotion and energy measures expenses) as "development costs" and all electricity siting measures expenses as "siting costs." Oshima then calculated the "unit development cost" and the "unit siting cost" by dividing development and siting costs by power output at nine electric utilities (excluding output at Okinawa Electric Power Co., Electric Power Development Co. (J-Power) and the Japan Atomic Power Co.).

Oshima's estimation used net output as the denominator. The relevant cost increase differentiates Oshima's estimation from Kunitake's approach. Estimation results for hydro, thermal and nuclear power generation under Oshima's approach are similar to those under Kunitake's approach, as indicated in Figure 2-2. The unit thermal power generation cost has been generally higher than the unit nuclear or hydro cost since 2000, and since 2005 the unit cost of thermal generation has increased in line with fossil fuel price hikes.
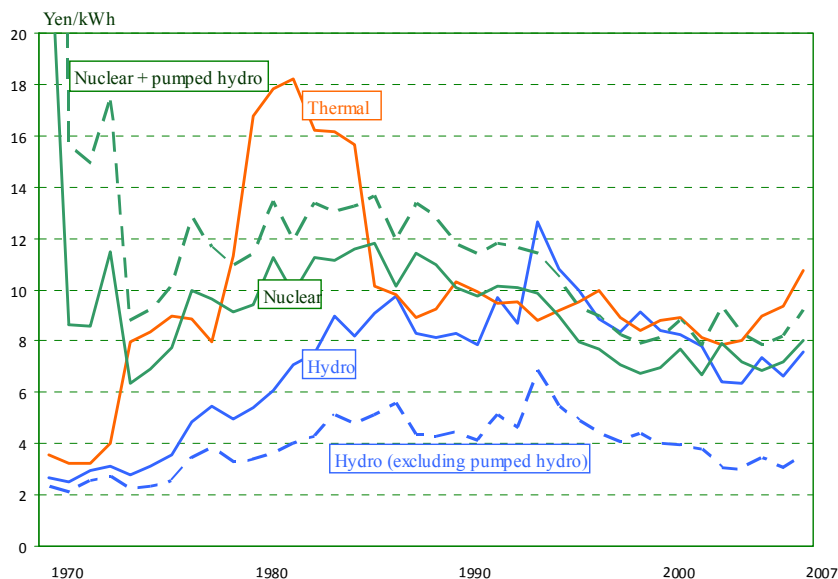

Figure 2-2 Unit Power Generation Cost Estimates Based on Corporate Financial Statements (Oshima 2010)

The unit development and siting costs are larger, particularly for nuclear power generation. As indicated in Table 2-1, the average unit development cost for the FY 2000-2007 period stood at 1.18 yen/kWh and the unit siting cost at 0.46 yen/kWh. They are combined with the unit power generation cost of 7.29 yen/kWh into the total unit cost of 8.93 yen/kWh, close to the total unit thermal power generation cost of 9.02 yen/kWh. If the pumped hydro generation cost is added, the total unit nuclear power generation cost rises to 10.11 yen/kWh, some 1 yen/kWh higher than the total unit thermal power generation cost.

Table 2-1 Total Unit Power Generation Cost for Each Generation Method in Oshima (2010)

Unit: yen/kWh

		Nuclear	Fossil	Hydro	Conventional hydro	Pumping-up hydro	Nuclear + pumping-up hydro
1970s	Unit power generation cost	8.85	7.11	3.56	2.72	40.83	11.55
	Unit development cost	4.19	0.00	0.00	0.00	0.00	4.31
	Unit siting cost	0.53	0.03	0.02	0.01	0.36	0.54
	Total unit cost	13.57	7.14	3.58	2.74	41.20	16.40
2000s	Unit power generation cost	7.29	8.90	7.31	3.47	41.81	8.44
	Unit development cost	1.18	0.01	0.10	0.05	0.60	1.21
	Unit siting cost	0.46	0.11	0.10	0.07	0.38	0.47
	Total unit cost	8.93	9.02	7.52	3.59	42.79	10.11
FY 2007	Unit power generation cost	8.05	10.73	7.58	3.58	45.34	9.19
FY 1970-2007 average	Unit power generation cost	8.64	9.80	7.08	3.88	51.87	10.13
	Unit development cost	1.64	0.02	0.12	0.06	0.94	1.68
	Unit siting cost	0.41	0.08	0.06	0.04	0.34	0.42
	Total unit cost	10.68	9.90	7.26	3.98	53.14	12.23

As noted above, the unit thermal power generation cost has increased rapidly in line with fossil fuel price hikes since 2005. Oshima estimated the unit power generation cost at 8.05 yen/kWh for nuclear, 10.73 yen/kWh for thermal and 9.19 yen/kWh for nuclear plus pumped hydro in FY2007. The unit thermal generation cost is remarkably higher than the unit nuclear generation cost. Although no specific unit development or siting cost in FY2007 is found in Oshima's estimates, the average development and siting costs for the FY2000-2007 period combined with the FY 2007 unit generation costs makes 10.9 yen/kWh for both thermal and nuclear plus pumped hydro total unit costs.

According to Oshima's estimates, the total unit cost for nuclear plus pumped hydro averaged 10.11 yen/kWh in the 2000s and 12.23 yen/kWh in the FY1970-2007 period. The latter average is over 2 yen/kWh higher than the former average. Various factors are conceivable behind the gap. Particularly, a major factor may be that the rate of return in FY1988 had been 7.2%, far higher than 3.0% at present. (Similarly, Kunitake et al. in Section 2-1 showed that the unit nuclear power generation cost levels in the 1970s and 1980s had been higher than the present level due to far higher long-term lending rates.) In order to assess more realistic power generation costs, we should adopt estimates close to the present levels.

2-3 Key points of the estimation approach using corporate financial statements
2-3-1 Comparison of the model plant and financial statement-using approaches

Table 2-2 indicates features of the cost estimation approach using corporate financial statements as compared with the approach using model plants. The financial statement-using approach's advantage is that the approach uses expenses required for actual electric utility business operations to estimate securer costs including less estimation or assumption. Since actual power generation facilities are constructed, amortized and operated over a long time, however, it is difficult to comprehensively estimate power generation costs based on corporate financial statements that specify actual single-year data alone. Financial statements for multiple years may be used to mitigate this disadvantage to some extent. But it is very difficult to estimate all the past costs since the construction of the first hydro power plant in 1880s consistently with price fluctuations taken into account.

We must also note that various electricity sources are mixed appropriately in actual electricity supply to minimize total system costs while meeting ever-changing demand. Estimates based on corporate financial statements reflect optimum systematic operations as capacity factors and operating costs but do not necessarily indicate indigenous costs for each electricity source.

Meanwhile, this approach is based on past actual data and conceived as useful for estimating past policies and analyzing business performances. If the above-mentioned constraints are acknowledged, the financial statement-using approach may be found as useful for providing important information for considering future electricity source choices. At the same time, we may then be required to use model plant method to compare source-by-source power generation costs and conduct sensitivity analyses under the same conditions.

It may be needless to say that a longer period for estimation may provide more information. When data in the far past are used, however, monetary value changes may have to be appropriately taken into account. In order to ascertain future implications, we may have to estimate the costs for the latest years, with recent fossil fuel price fluctuations and other developments taken into account.

Table 2-2 Comparison of Cost Estimation Approaches

|	Outline	Example	Advantage	Disadvantage (limit)
Model plant approach	A model plant for each electricity source is assumed along with appropriate unit construction cost, fuel cost, operation and maintenance cost, discount rate, etc. to estimate the unit power generation cost per kilowatt-hour.	Subcommittee to Study Costs and Other Issues (2004) OECD "Projected Costs of Generating Electricity" (2010) MIT "The Future of Nuclear Power" (2003,2009), etc.	Electricity sources can be compared under the same economic conditions or business environments, excluding characteristics of electricity sources. Therefore, the approach is useful for selecting future electricity sources.	Depending on model plant specifications and individual construction and operation conditions, estimation results may not necessarily be identical to actual data.
Financial statement-using approach	Actual power generation costs for each fiscal year are assessed based on data (operating cost for hydro, fossil and nuclear power generation, fixed assets, etc.) in corporate financial statements published by electric utilities.	Kunitake et al. (1999) Oshima (2010), etc.	The approach uses data for actual business operations and is persuasive. Assessment covering multiple years enables fluctuating factors be analyzed. The approach is useful for assessing past policies and analyzing past business performances.	Long-term costs for construction and amortization of power plants are viewed only for single years. Therefore, this approach cannot necessarily provide useful, accurate information for selecting future electricity sources.

2-3-2   Treatment of hydro power generation

As indicated by cases given in Sections 2-1 and 2-2, the estimates based on corporate financial statements show that the unit hydro power generation cost remained lower than the unit nuclear or thermal generation cost until the mid-1980s, rose slightly later, and is now close to the nuclear or thermal level. Particularly, the unit cost for conventional hydro power generation (i.e. excluding pumping generation) is very low as estimated under Oshima's approach. But hydro power generation facilities now in operation have mostly been amortized. Therefore, we must pay attention to the fact that the financial statement-using approach cannot estimate construction costs for hydro power generation facilities. This defect is serious when costs are estimated for power generation method like hydro, that features high initial construction costs and no fuel costs.,

As indicated by Figure 2-3, some 30% of conventional hydro power generation facilities entered operation in or before the 1940s[14]. In the 1950s, many hydro power generation facilities were launched. Since the 1970s, however, fewer hydro power plants have been launched. Many old hydro power plants are still in operation with components replaced, but many hydro power plants (excluding pumping plants) might have already completed their amortization. Therefore, their construction costs cannot be estimated appropriately in analyses using corporate financial statements. Meanwhile, a substantial part of hydro power plants built in and after the 1960s adopted the pumping-up method and are responsible for a rise in the unit hydro power generation cost since the second half of the 1980s as indicated in Figures 2-1 and 2-2 under the approach using corporate financial statements. Comparing years for launching hydro power plants in Figure 2-3 and those for starting thermal and nuclear power plants in Figure 2-4, we can easily find that we should not treat hydro and thermal/nuclear plants equally from the viewpoint of amortization.

The above indicates that the approach using corporate financial statements allows us to estimate expenses required for real business management as actual costs, while failing to accurately estimate long-term costs for construction and amortization. The failure is emphasized particularly for hydro power generation in Japan. The fact that hydro power plants built before World War II are still in operation far after their amortization may indicate an advantage of hydro power generation, but the unit hydro power generation cost covering these old plants as well may be estimated only through model-based calculation based on appropriate service life assumptions, rather than through the approach using corporate financial statements.

For the above reason, we hereinafter focus on comparison of the unit thermal and nuclear power generation costs. But we must take in mind that the above problem may also affect these costs, though to a less extent.
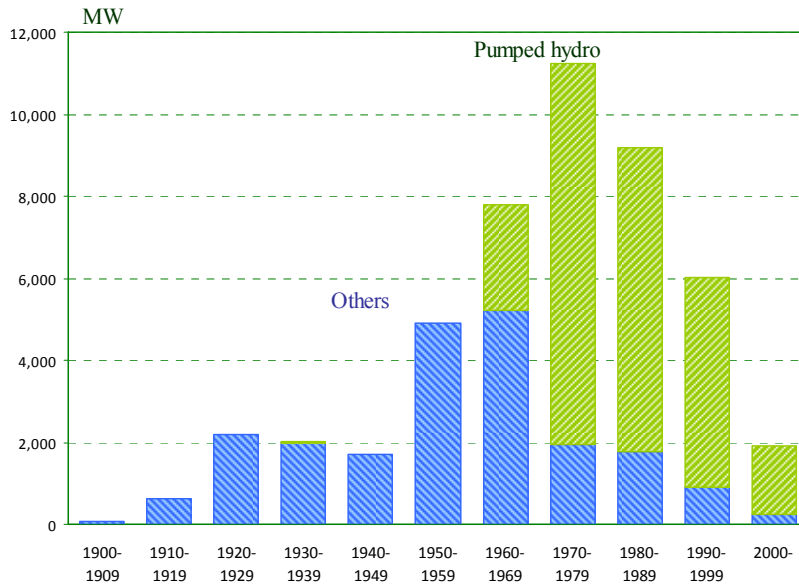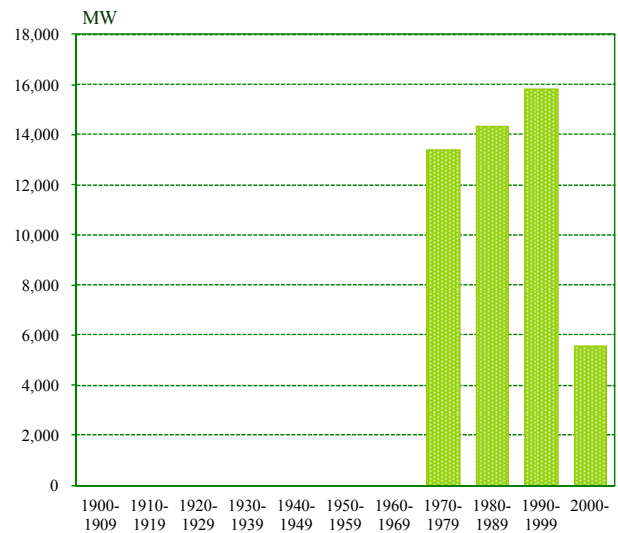
Source: Electric Power Civil Engineering Association, "Hydro Power Plant Database"

Figure 2-3 Years of Launching Hydro Power Plants (general power and wholesale electricity utilities)
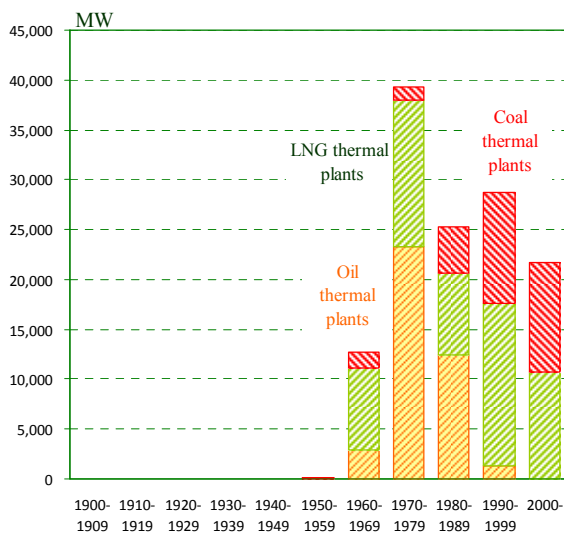
Thermal power generation

Nuclear power generation

Source: Ministry of Economy, Trade and Industry, "FY 2009 Electricity Demand Overview"; IEEJ, "Handbook of Energy & Economic Statistics in Japan

Figure 2-4 Years of Launching Thermal and Nuclear Power Plants
**(general power and wholesale electricity utilities)**

      Oshima insisted that the unit power generation cost for nuclear plus pumped hydro, instead of nuclear alone, should be used for estimating nuclear power generation costs because pumped hydro facilities were built in a manner to accompany the massive introduction of nuclear power generation where power output cannot be adjusted.

      In fact, Japan's electricity supply system classifies nuclear, must-run hydro, geothermal and coal thermal power plants as basic power sources, LNG thermal power plants as middle power sources, and oil thermal and

pondage/storage/pumping-up hydro power plants as peak-demand power sources. It is incorrect to recognize that pumped hydro power plants must always be operated to consume surplus nighttime nuclear plant output that cannot be adjusted. As far as coal thermal, nuclear and must-run hydro power plants are classified as basic power sources, pumped hydro power generation costs may have to be appropriately distributed to these sources, if any. Then, pumped hydro plants' cost portion for peak-demand power sources may have to be excluded, because pumped hydro power generation not only helps adjust the nighttime electricity supply/demand balance but also supplies electricity at demand peaks, and in this sense pumped hydro power generation thus substitutes for oil thermal power generation, for example.

Furthermore, the effective electricity storage capacity of pumped hydro power plants is also expected to play a role in solving the destabilization of power grids on the massive introduction of photovoltaic, wind power and other renewable energy power generation. In this sense, it is inappropriate to include all capital costs for existing pumped hydro power plants into nuclear power generation costs.

Solutions to power grid destabilization accompanying a mismatch between electricity supply and demand are very important when future electricity supply is considered. Various solutions have been considered, including the improvement of electricity storage capacities such as pumped hydro power generation, the enhancement of power grids, the adjustment of nuclear plant output, the control of photovoltaic and wind power plant output, and the leveling of electricity demand. The selection of solutions or technologies to stabilize power grids and their respective costs depend on future technology development trends and must be considered separately from power generation methods. Costs for power grid stabilization measures, though closely linked to power generation methods, may have to be viewed as a separate issue.
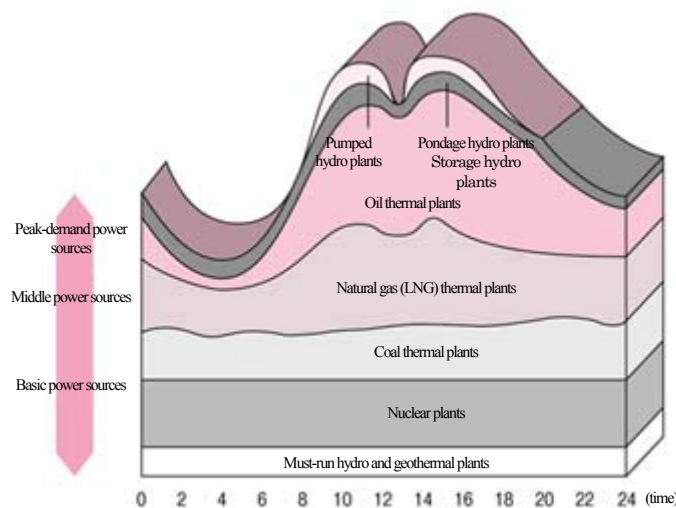
Source: Chubu Electric Power Co. website

Figure 2-5 Electricity Supply Scheme in Japan

2-3-3 Development and siting costs

As noted earlier, Oshima included the average unit development cost of 1.18 yen/kWh and the average unit siting cost of 0.46 yen/kWh for the 2000s into the total unit nuclear power generation cost. This approach may be designed to reflect all social costs including research and development expenses for nuclear power generation. But nuclear plant research and development costs cover fast breeder reactors, high-temperature gas-cooled reactors, nuclear fusion and other cutting-edge technologies as well as light water reactors now in operation. Even if social costs for the present nuclear power generation are estimated to the maximum extent, it is not appropriate to include all such costs into the total unit unclear power generation cost, considering the fact that a cut in budget outlays for cutting-edge nuclear technology research and development will have no problem with the operations of current nuclear power stations.

Table 2-3 indicates the unit development cost for "new energies" (PV, wind, geothermal etc.) as estimated based on the development cost given by Oshima. The estimated unit development cost for new energies is very high, exceeding 10 yen/kWh. This is partly because power generation with new energies is limited, but this can also be interpreted as suggesting

that technology development for the future should be considered as a matter separate from costs for power generation using existing technologies. For example, it is difficult to conclude that the inclusion of research and development outlays for space photovoltaic power generation and other cutting-edge technologies into the unit power generation cost for solar panels contributes to an accurate assessment of photovoltaic power generation costs. This may be the same case with nuclear power generation. Most nuclear research and development outlays may be designed for cutting-edge technologies that are different from long-existing nuclear power generation technologies, and it is not easy to give any specific ground for assessing the extent to which these outlays should be included into the unit nuclear power generation cost.

Table 2-3 Unit Development Cost for Nuclear and "New Energies"

Unit: yen/kWh

	Nuclear	New energies
1970s	4.19	10.21
1980s	2.26	25.13
1990s	1.49	15.88
2000s	1.18	11.11

Note: We calculated the unit development cost for new energies by dividing development costs by the total output of geothermal, wind power and photovoltaic power plants.
Source: Prepared by the author from Oshima (2010), etc.

2-4   Estimation approach for this study

As noted in Section 2-3-1, the approach using corporate financial statements has difficulties estimating overall power generation costs consistently over a long period of time, while featuring an advantage that securer costs including less estimation can be calculated based on actual data for relevant business years.

As indicated by Figure 2-1, interest payments' contributions to the unit power generation costs may not be negligible but may be indispensable for estimating accurate costs. Meanwhile, the approach indicated in Section 2-2 included a rate base multiplied by a rate of return into the unit power generation cost, based on power utilities' cost calculations. By using the assumed rate of return to calculate the business return indicating social costs for power generation, this approach apparently affects the above-mentioned advantage of the financial statement-using approach. (Calculations using such assumed or presumed values belong to model estimation and should be done with a model plant calculation method.)

For the above reasons, this study estimated a combination of electric utility operating expenses and interest payments mainly in accordance with Kunitake's approach given in Section 2-1. Secondarily, some estimations according to Oshima's approach described in Section 2-2 are conducted.

In line with Kunitake's approach, interest payments are distributed to power generation methods according to each method's share of electric utility fixed assets and construction in progress account. As the denominator of the division to compute unit costs, the net output excluding utilities' on-site consumption is used, instead of the gross output adopted by Kunitake et al.

As detailed lists of electric utility operating expenses specify details of expenses, we can classify expenses into several categories. We classify these expenses here in accordance with Table 2-4. Distributed interest payments are included into capital costs.

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Table 2-4 Classification of Power Generation Costs Specified in Detailed Lists of Electric Utility Operating Expenses

Category	Classification in the Detailed List
Capital cost	Fixed asset tax, amortization expenses, losses on retirement of fixed assets, contributions for shared
Fuel cost	Fuel expenses
Backend cost	Spent fuel reprocessing expenses, spent fuel reprocessing preparation expenses, waste disposal expenses, specified radioactive waste disposal expenses
Decommissioning cost	Nuclear power generation facility dismantlement expenses
Operational and maintenance cost	All expenses other than the above

Subjected to the estimation were 12 general and wholesale power utilities. In a bid to assess more realistic power generation costs, we estimated average values for the five latest years (FY2006-2010). Authors' estimation thus reflects fossil fuel price spikes in FY 2008 and later developments, allowing us to analyze the relationship between fossil fuel price fluctuations and power generation costs to ascertain future implications.

These companies' financial statements specify power output covering consolidated subsidiaries, while source-by-source electric utility operating expenses are given only in unconsolidated financial statements. The above-mentioned approach thus fails to cover expenses at consolidated subsidiaries, leading thermal and hydro power generation costs underestimated. Here, we excluded power output at consolidated subsidiaries from the total output according to their power generation capacity shares, only for cases where the capacities are specified.

We used the same approach to estimate the unit power generation cost for "new energies" as financial statements of these firms specified expenses for this kind of power generation in addition to hydro, thermal and nuclear energies in FY 2009 and 2010. New energies here include geothermal, wind power, solar energies, etc, but because of the amount of the electricity generated, the "new energy" generating cost calculated here is considered to represent that of geothermal energy. Therefore, we will hereinafter call this category "geothermal, etc."

J-Power had 15 MW in geothermal power generation capacity with consolidated subsidiaries' wind power generation capacity at 352.9 MW in FY 2010. It may be needless to say that straightforward calculations will lead us to substantially underestimate new energy-based power generation costs as stated above. But if consolidated subsidiaries' power output is excluded according to their capacity shares, the gap in capacity factor between geothermal and wind power plants may lead us to overestimate the generation costs. In estimating power generation costs for "geothermal, etc.", therefore, we excluded J-Power and adopted an average for 10 general power utilities alone.

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3.   Estimation Results

The average unit power generation cost for the FY2006-2010 period for the 12 companies (J-Power is excluded for geothermal, etc.) came to 10.2 yen/kWh for thermal, 7.2 yen/kWh for nuclear and 8.9 yen/kWh for geothermal etc. as shown in Figure 3-1. The thermal power generation cost was the highest. Fuel cost accounted for 7.5 yen/kWh or 74% of the thermal power generation cost. The reason for the high cost is undoubtedly a fuel price hike accompanying a crude oil price spike.

The unit nuclear power generation cost of 7.2 yen/kWh includes 1.9 yen/kWh in capital cost, 0.6 yen/kWh in fuel cost, 2.7 yen/kWh in operation and maintenance cost, 1.8 yen/kWh in backend cost and 0.3 yen/kWh in reactor decommissioning cost. Nuclear power generation thus features a far cheaper fuel cost than thermal power generation. Meanwhile, the backend cost makes great contributions to the overall nuclear power generation cost. According to the OECD's model-based cost estimation, the backend cost (covering transportation, storage and reprocessing of spent fuels, and waste disposal) is calculated at 0.23 cent/kWh[15]. Given actual Japanese data, OECD's estimate is interpreted as indicating an underestimation. Most of the backend and decommissioning costs accumulated on an actual data basis are based on reserves set aside by the companies for the future. We must recognize that these costs would be different from costs for actual decommissioning of nuclear reactors and disposal of radioactive wastes. Therefore, a detailed analysis of backend and decommissioning costs will become a very important challenge in the future.
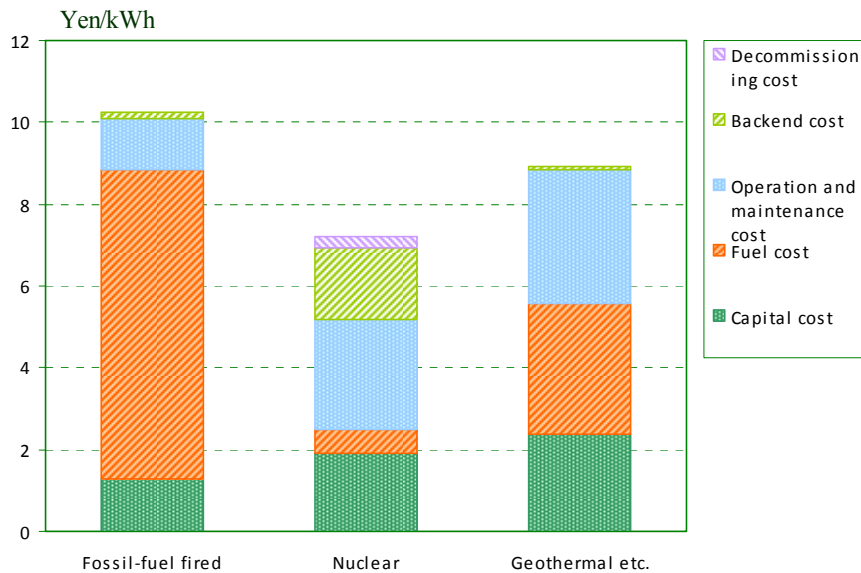

Figure 3-1 Power Generation Costs by Source (FY2006-2010 average)

Figure 3-2 indicates time-series changes in the unit nuclear power generation cost (the average for 10 companies with nuclear power generation facilities). The unit cost was lower when the capacity factor was relatively higher, and higher when it was lower. On average, the unit cost remained stable around 7 yen/kWh, as shown by the figure.
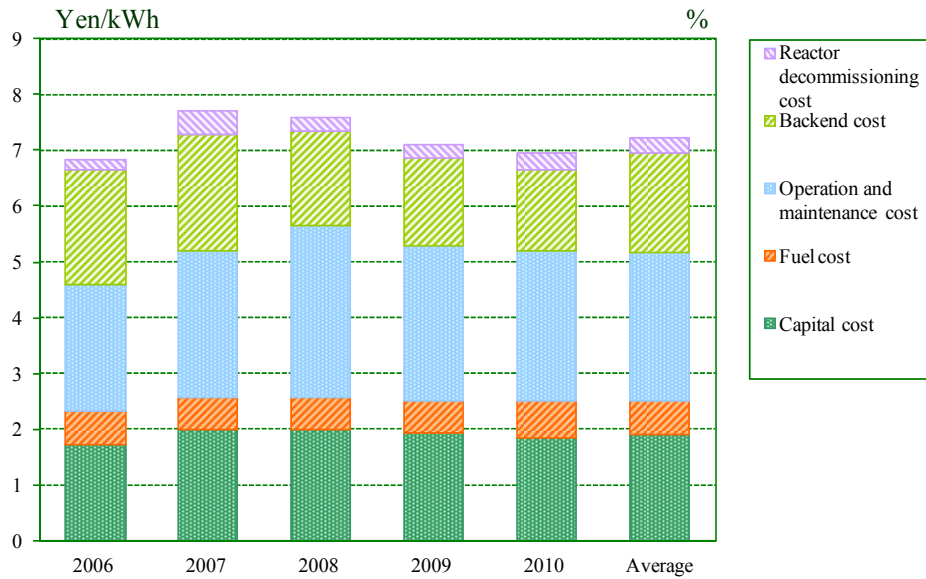
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Yen/kWh   %

Figure 3-2 Unit Nuclear Power Generation Cost (average for all firms)

Figure 3-3 indicates the average operating year of nuclear power plants shown by the horizontal axis and their average capital cost shown by the vertical axis for each electric utility. The figure suggests that a longer operating year works to reduce the capital cost through amortization. The 10 firms' average operating year for nuclear plants stands at around 23 years and their average capital cost at around 1.9 yen/kWh. These data lead us to suspect that amortization of nuclear plants has made progress on average. As for nuclear power plants, the average capital cost over a operating period (e.g., 40 years) between the service launch and termination should be adopted. An accurate estimation of the capital cost over a service life may have to be calculated with the model plant approach.
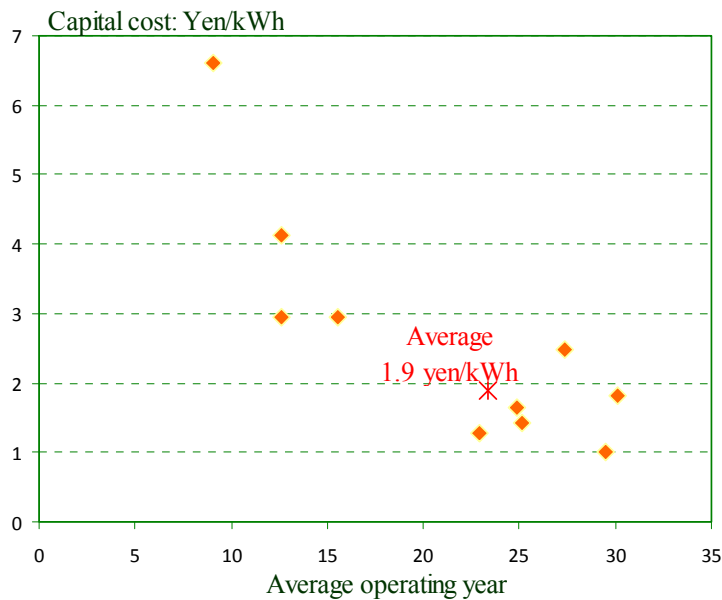

Figure 3-3 Relationship between Nuclear Reactor Operating Years and Capital Costs

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Figure 3-4 indicates the trends of the unit thermal power generation cost (the average for 11 companies with thermal power plants) along with those of the benchmark crude oil import price (on a C.I.F. basis)[16] viewed as a main energy price indicator in Japan. Thermal power generation cost fluctuations have almost been defined by fuel price changes that have been linked to crude oil price fluctuations, as shown in the figure. In FY2008, the fuel cost accounted for 9.8 yen/kWh or 78% of the total unit thermal power generation cost that reached 12.5 yen/kWh.

In this way, the unit thermal power generation cost has wildly fluctuated in line with primary energy price changes amid crude oil price spikes since 2004. Although U.S. natural gas prices have fallen on sharp progress in shale gas development over recent years, the U.S. change has failed to affect Japan where imported LNG prices have been linked to crude oil prices. Meanwhile, primary energy prices are expected to continue an upward trend in the world as natural gas demand continues a steep expansion over a long term in emerging countries such as China and India[17][18][19][20]. The unit thermal power generation cost is estimated to rise to 14 yen/kWh if the benchmark crude oil price rises from $60.4/bbl in 2009 to $115/bbl (in 2009 prices) in 2035 as forecast in the IEEJ outlook[20], with other primary energy prices following suit. If carbon dioxide emissions are priced in some form on progress in global warming measures, the emission cost may be included into the thermal power generation cost. Given the above, any excessive dependence on thermal power generation is expected to post great threats to national energy security.
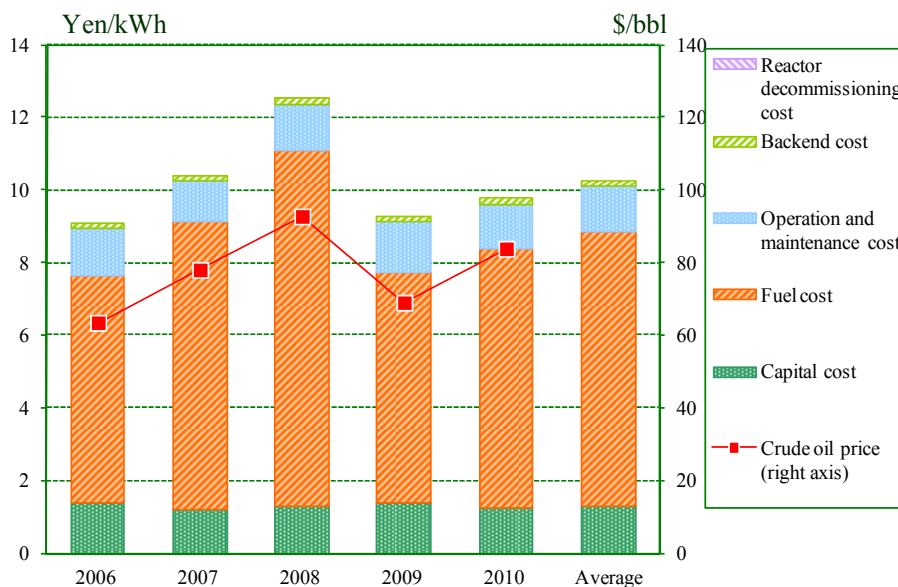

Figure 3-4 Thermal Power Generation Cost (on average for all firms)

Figure 3-5 shows changes in the gap between the unit thermal and nuclear power generation costs. The average gap over five years came to 3.0 yen/kWh. In FY2008 when crude oil prices soared, the gap widened to 4.9 yen/kWh. Even if the pumped hydro power generation cost of 1.1 yen/kWh and the development and siting cost of 1.7 yen/kWh are included into the unit nuclear power generation cost, the nuclear cost may be almost equal to the unit thermal power generation cost on a five-year average basis and may slip far below the thermal cost upon fossil fuel price spikes.
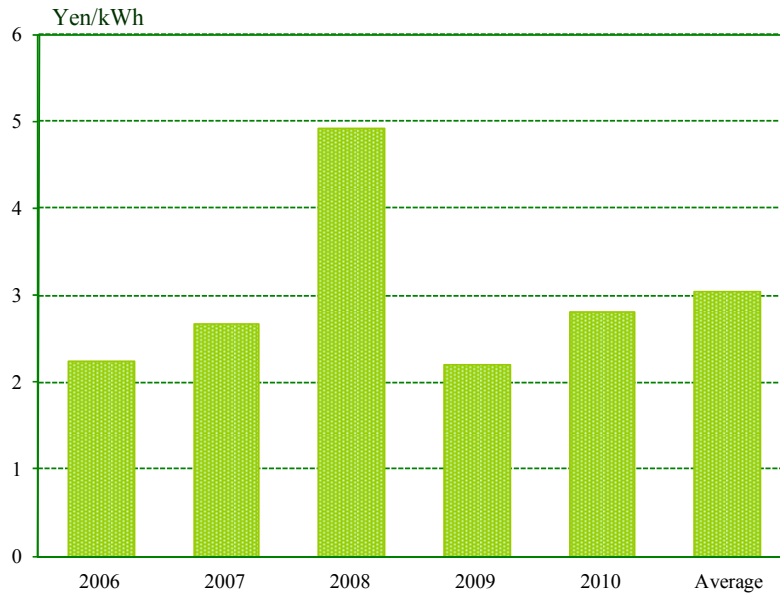
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Yen/kWh

Figure 3-5 Gap between Thermal and Nuclear Power Generation Costs

Figure 3-6 outlines gaps between Oshima's estimates (on a FY1970-2007 average basis) and authors' estimates. The Oshima-estimated thermal power generation cost is almost equal to authors' estimate (on a FY2006-2010 basis) as the former estimate covers data during the past oil crises while failing to reflect the recent crude oil spikes.

But the Oshima-estimated nuclear power generation cost differs far from authors' estimate. The largest factor behind the difference is the gap in the period for estimation. As described above, calculation on a FY1970-2007 average basis overestimates unit nuclear power generating costs due to large fluctuations in interest rates and rates of return.

Oshima estimates the development cost at 1.3 yen/kWh, the siting cost at 0.5 yen/kWh and the pumped hydro power generation cost at 1.2 yen/kWh on a FY2000-2007 basis as part of the total unit nuclear power generation cost. The difference between the interest rate-using and rate of reutrn-using approaches is estimated to result in a gap of around 0.5 yen/kWh. The total gap comes to 5 yen/kWh.

For the above-mentioned reasons, the inclusion of all pumped hydro power generation and development costs into the unit nuclear power generation cost is expected to produce an overestimate. Meanwhile, the siting cost can provide useful information for power generation's load on the whole of Japanese society. If this is included, the unit nuclear power generation cost comes to 7.7 yen/kWh.
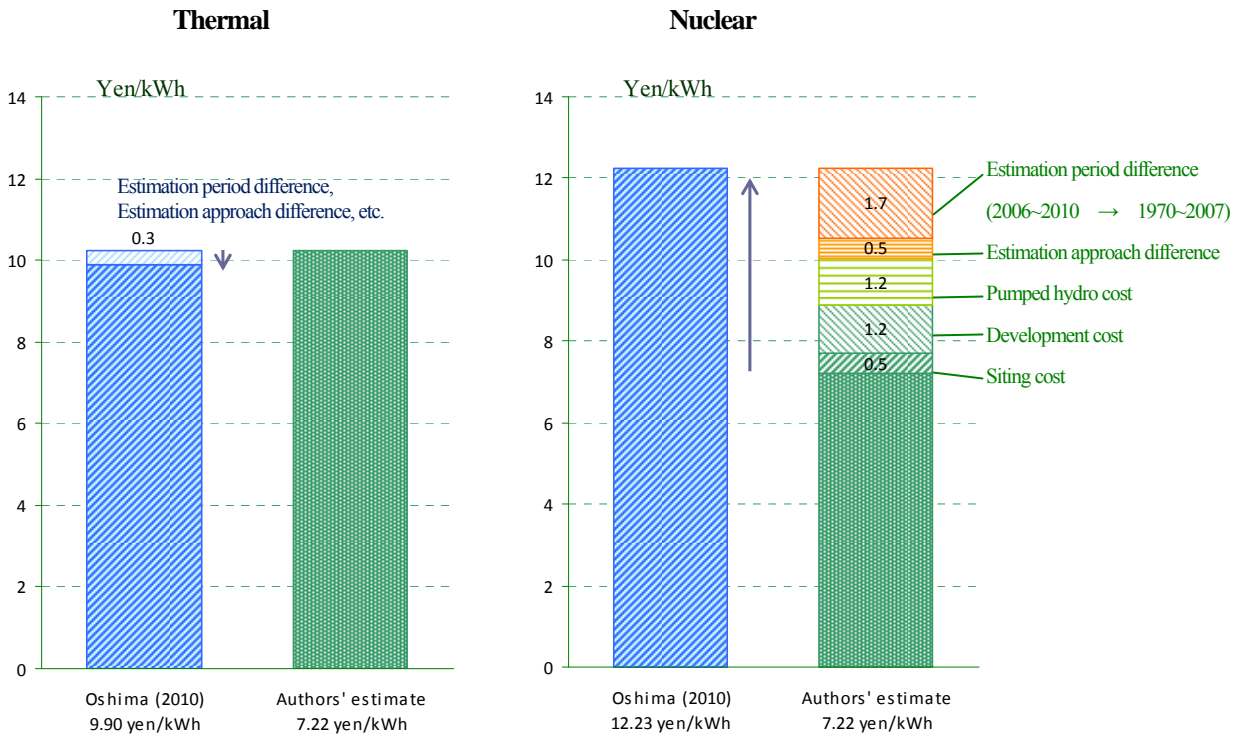
Thermal

Nuclear

Figure 3-6 Gaps between Oshima (2010) and authors' Estimates

Figure 3-7 indicates the unit geothermal, etc. power generation cost. The unit cost came to 8.4 yen/kWh in FY2009 and 9.5 yen/kWh in FY2010, slipping below the thermal power generation cost. As indicated by Table 3-1, however, no new geothermal power plants have been built since many such plants launched operations in the 1990s, indicating that the capital cost might have been underestimated due to amortization. Anyway, the power generation cost of geothermal, etc. may have to be estimated accurately after more data are collected in addition to those for FY2009 and 2010.
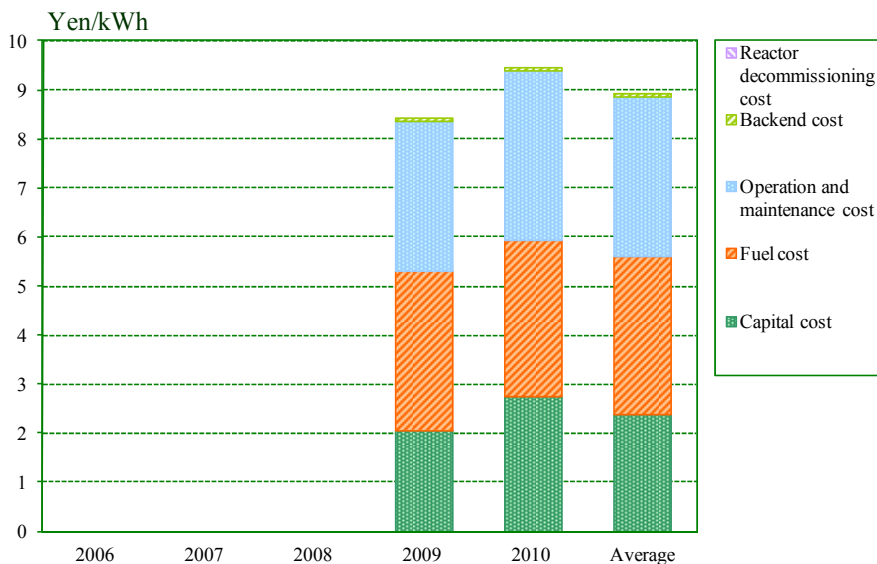

Figure 3-7 Geothermal etc. Power Generation Cost (average for all excluding J-Power)

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Table 3-1 Geothermal Power Plants of Tohoku and Kyushu Electric Power

Tohoku Electric Power Co.

Name	Year of launching	MW
Uenotai geothermal plant	1994	28.8
Kakkonda geothermal plant unit 1	1978	50
Kakkonda geothermal plant unit 2	1996	30
Sumikawa geothermal plant	1995	50
Yanaizu Nishiyama geothermal plant	1993	65
Total		223.8

Kyushu Electric Power Co.

Name	Year of launching	MW
Otake power plant	1967	12.5
Hatchobaru unit 1	1977	55
Hatchobaru unit 2	1990	55
Yamakawa power plant	1995	30
Takigami power plant	1996	27.5
Ogiri power plant	1996	30
Total		210

Sources: Company websites

Figure 3-8 gives estimation results under the approach using the rate of return as outlined in Section 2-2. Small differences between Oshima's and authors' estimates for FY2006 and 2007 are attributable to a gap in the coverage of electric power generation companies. While Oshima's estimates cover only nine general power utilities excluding Okinawa Electric Power Co., authors' estimates include J-Power for hydro power generation, Okinawa Electric Power and J-Power for thermal power generation and Japan Atomic Power Co. for nuclear power generation.

Like earlier estimates, the estimation results indicate that the thermal power generation cost increased in line with crude oil price spikes. Its gap with the nuclear power generation cost in FY2008 reached 4.5 yen/kWh. Even under this approach, estimates based on corporate financial statements indicate that even if development and siting costs are included into the nuclear power generation cost, the thermal power generation cost exceeds the nuclear cost upon fossil fuel price spikes.
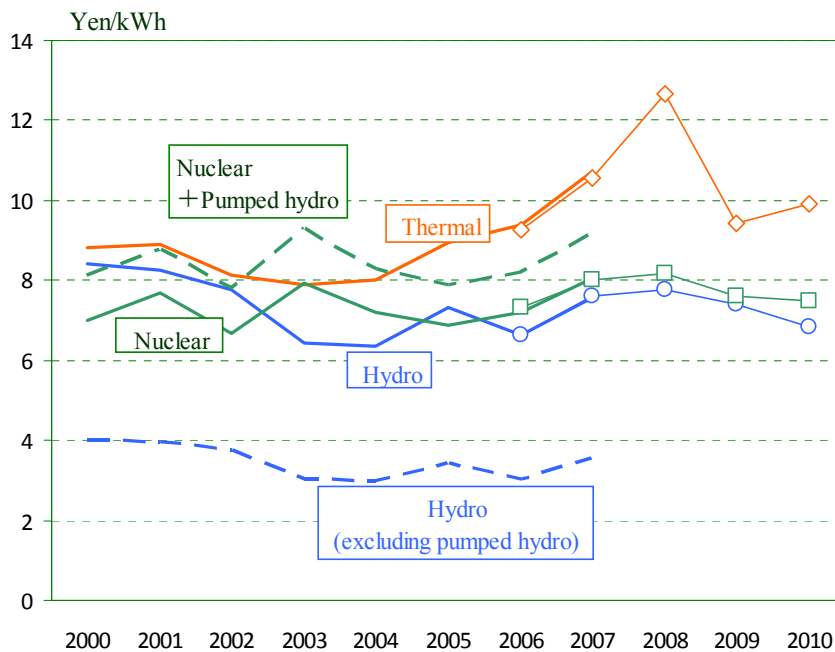

Figure 3-8 Power Generation Cost Estimation Using the Rates of Return
(Oshima's estimates for FY2000-2007 and authors' estimates for FY2006-2010)

4.   Comparison between Authors' and Other Power Generation Cost Estimates

As explained above, the power generation cost estimation approach using corporate financial statements, though having some methodological problems, apparently provides useful information at least when thermal and nuclear power generation costs are compared. Comparing authors' estimates with others including the OECD's estimates under a representative approach using model plants, this chapter analyzes key points for estimating power generation costs.

Figure 4-1 indicates the OECD's power generation cost estimation results for Japan. The estimation used the uniform discount rates of 5% and 10% for all research target countries. Generally, the higher discount rate leads to relatively higher costs for nuclear and renewable energy power generation that features high initial investment costs. The nuclear power generation cost comes to 5.0 cents/kWh at the discount rate of 5% and 7.6 cents/kWh at 10%, slipping below the thermal power generation cost excluding the carbon cost (estimated at $30 per ton of carbon dioxide). The OECD literature indicates the carbon cost at 2.4 cents/kWh for coal power generation and 1.1 cent/kWh for natural gas power generation. If such cost is included into the thermal power generation cost, its gap with the nuclear power generation cost widens. Meanwhile, the hydro power generation cost comes to 15.3 cents/kWh at the discount rate of 5% and 28.2 cents/kWh at 10%, far higher than the thermal or nuclear power generation cost.

As discussed above, the hydro power generation cost based on corporate financial statements is substantially underestimated due to the amortization problem. The actual hydro power generation cost may be as high as indicated by the OECD model-based estimates. Meanwhile, OECD-estimated thermal and nuclear power generation costs are lower than those based on corporate financial statements. One reason for the gap may be that the OECD has set the fossil fuel price at a level lower than at present. The OECD prices LNG at $11.09/MMBtu, or $574/t, and steaming coal at $90/t. Japan's C.I.F.-based imported LNG price came to $656.82 in FY2008 and $462.33/t in FY2009, while its C.I.F.-based imported steaming coal price stood at $137/t in FY2008 and $98/t in FY2009[16]. Particularly, OECD-set prices for coal may be lower than actual levels.

As for nuclear power generation, the OECD might have assumed the backend cost at a lower level and the unit construction cost at $3,009/kW, lower than the actual level in Japan. These problems might have to be verified further. A comparison between the OECD estimates and authors' estimates based on corporate financial statements in this paper apparently indicates that the OECD-estimated nuclear power generation cost for Japan may be slightly lower than the actual level.

In considering future nuclear power generation costs, we will have to take into account possible increases in backend costs (including costs for reprocessing of spent nuclear fuel and final disposal of radioactive wastes) and damage compensation accompanying nuclear plant accidents. If such damages are assumed at 10 trillion yen and divided by 7.55 trillion kWh, Japan's total nuclear power generation between FY1965 and 2010, the average damage payment cost comes to about 1.3 yen/kWh. The estimation of nuclear power generation costs including such cost-boosting factors is an important challenge that must be considered in detail in the future.
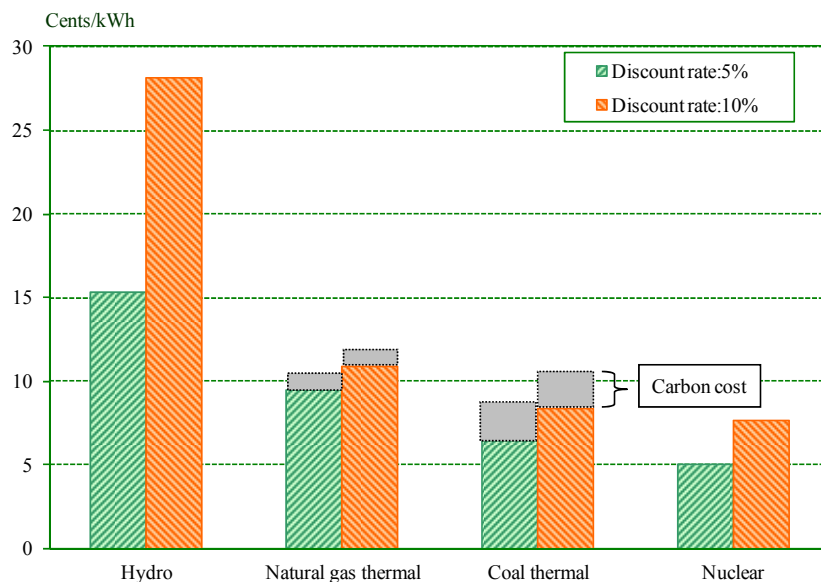

Figure 4-1 Power Generation Cost Estimates for Japan (OECD, 2010)

Figure 4-2 indicates OECD estimates for the United States and Germany. The estimates for the two countries are

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slightly different from those for Japan because of gaps in unit construction costs and fossil fuel prices. If the carbon tax and the like are not taken into account, the nuclear power generation cost in the United States or Germany is estimated to be almost equal to the unit thermal power generation cost. The nuclear cost is slightly higher than the coal power generation cost. Meanwhile, renewable energy power generation costs are generally higher. Particularly, the U.S. solar photovoltaic power generation cost, which is the lowest among the three countries, is estimated at 22 cents/kWh at the discount rate of 5%, far higher than for other power generation methods. At the same time, geothermal energy is the cheapest power generation source with the cost at 3.2 cents/kWh at the discount rate of 5% in the United States. The onshore wind power generation cost is lower than the thermal or nuclear cost in the United States. Japan's geothermal etc. power generation cost, given in this study, indicates that the renewable energy power generation cost could be equal to or lower than the thermal power generation cost depending on conditions. As shown by Figure 4-2, however, Germany's onshore wind power generation cost is double the U.S. level. We must pay attention to the fact that the renewable energy power generation cost could be equal to or lower than the thermal power generation cost only under favorable conditions.
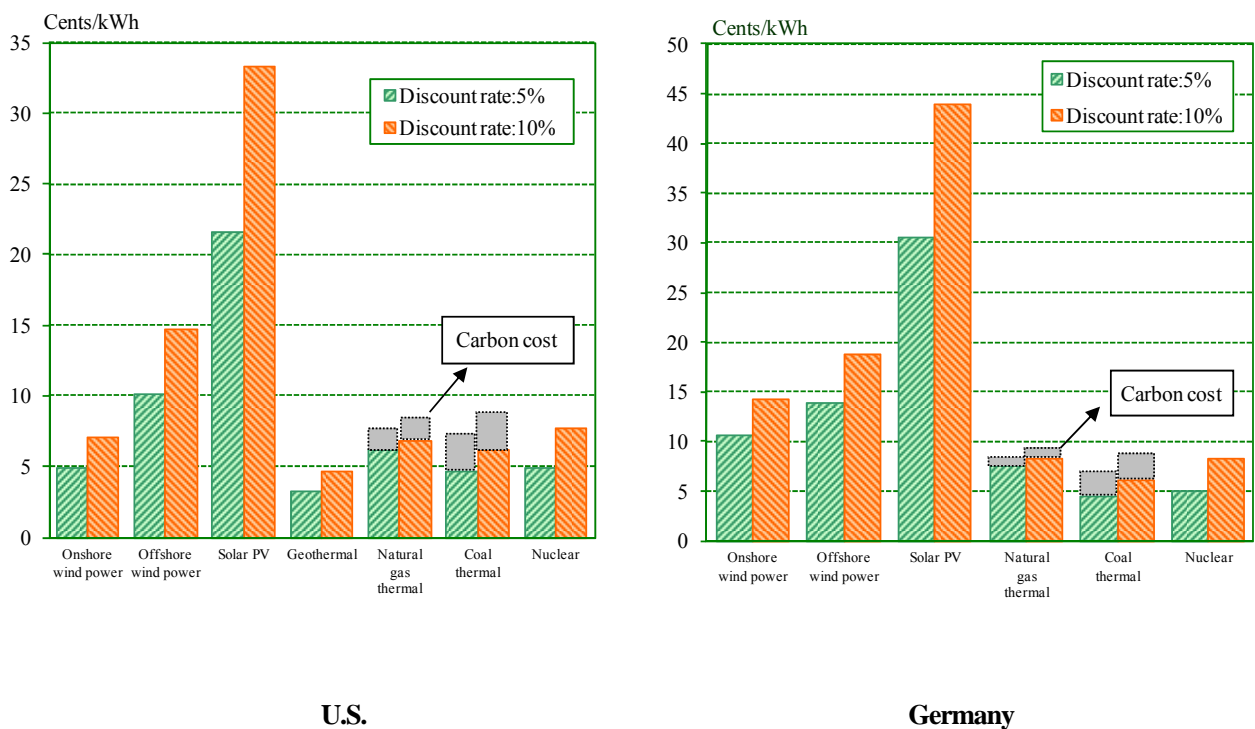

U.S.   **Germany**

Figure 4-2 U.S. and German Power Generation Cost Estimates (OECD, 2010)

Figure 4-3 indicates nuclear and photovoltaic power generation costs as estimated by Blackburn & Cunningham[21]. These authors used model calculation to estimate nuclear and photovoltaic power generation costs, concluding that nuclear and solar photovoltaic costs were equal at 16 cents/kWh and that the solar photovoltaic cost would fall further while the nuclear cost would rise further. In this estimation, the photovoltaic power generation cost was estimated to decline by 19 cents/kWh from the actual level of 35 cents/kWh to 16 cents/kWh due to federal and state government subsidies. This means that the actual cost without government subsidies was 35 cents/kWh, significantly higher than the nuclear power generation cost. The estimation was made for North Carolina with the capacity utilization rate put at 18%. Given the capacity utilization rate of 12% in Japan, the cost would be higher.

As for nuclear power generation, Blackburn & Cunningham have taken into account a recent rise in the construction cost in the United States. As the United States has been very slowly preparing for its first nuclear plant construction in decades, the unit construction cost for first new nuclear plants in decades has been rising. If nuclear plant construction continues until around 2020, the cost-boosting factor may weaken. Therefore, the nuclear power generation cost estimate at present in Figure

4-3 may be viewed as an overestimate over a long time. There may be little ground for projecting the nuclear power generation cost to rise persistently from now on.
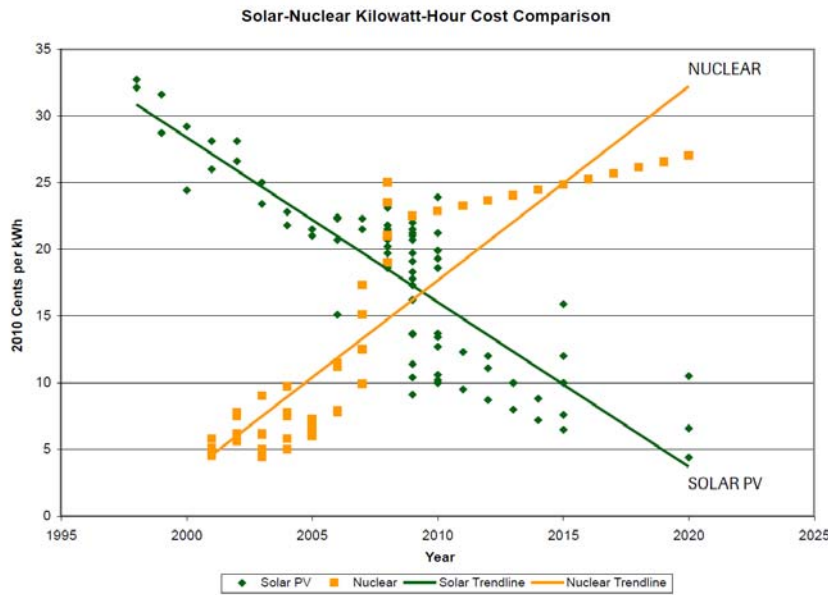

Figure 4-3 Estimated Photovoltaic and Nuclear Power Generation Costs
(Blackburn & Cunningham, 2010)

5.　　Conclusion

　　　　This paper estimated thermal and nuclear power generation costs using corporate financial statements for the past five years, while referring to past research approaches. Based on actual costs in these statements, we found that nuclear power generation cost less than thermal power generation when fossil fuel prices soared. The actual data have demonstrated that while thermal power generation is directly affected by fluctuations of the fuel cost accounting for more than 70% of the total cost, nuclear power generation is invulnerable to fossil fuel price fluctuations.

　　　　Fossil fuel prices are expected to continue an upward trend over a long time as energy demand grows rapidly mainly in Asian developing countries. In such case, the thermal power generation cost is expected to rise inevitably. Destabilization of fossil fuel supply and wild fluctuations of fossil fuel prices may have to be considered from the viewpoint of energy security. The thermal power generation cost is expected to rise further due to a carbon cost if global warming measures make progress. (The OECD estimates the carbon cost at 2-3 cents/kWh for coal power generation and at 1 cent/kWh for natural gas power generation.) Meanwhile, the fuel cost's share of the total unit nuclear power generation cost is smaller. Uranium enrichment service costs are unlikely to increase so much as new large uranium enrichment facilities are expected to become operational. Even if natural uranium prices soar, therefore, its impact on the overall nuclear power generation cost may be relatively limited. But such future cost-boosting factors as the enhancement of safety, damage payments accompanying nuclear accidents, and decommissioning and backend cost increases cannot be estimated with the approach using corporate financial statements. They can never be ignored. The Oshima-estimated nuclear power generation cost inappropriately includes all of pumped hydro power generation, development and siting costs, resulting in an overestimate. But some (including the siting cost) of the additional costs may be interpreted as representing necessary costs accompanying nuclear power generation. Their inclusion could be appropriate depending on estimating approaches. Given all these problems, efforts should be continued to comprehensively and accurately estimate power generation costs.

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Contact: report@tky.ieej.or.jp