Historical Trends in Japan’s Long-Term Power Generation Costs by Source: Assessed by Using Corporate Financial Statements

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Abstract

This paper uses corporate financial reports for nine power companies over a period of 42 years from fiscal 1970 to 2011 to assess the cost of hydro, thermal and nuclear power generation and its breakdown in terms of actual values across a long time series. By comparing the results with the estimation results of the Cost Review Committee, the authors have, on the one hand, assessed the differences between the Committee’s estimation values and long-term actual values, and on the other hand, confirmed that the Committee’s results are closer to actual past values than the results in the OECD report, which diverge significantly in terms of the cost of nuclear power generation in Japan, and that it is on the whole appropriate to discuss future energy policies based on the Committee’s work despite some apparent problems.

By assessing the cost of power generation over a long period, the authors also confirmed that compared to the time of steep increases in the price of crude oil in the 1980s, the diversification of energy supply sources paid off when prices rose steeply again after 2005, and that the rise in the cost of power generation was actually mitigated. However, following the Fukushima Daiichi nuclear power plant accident at the end of fiscal 2010, the power generation mix in Japan again became more concentrated with the decrease in nuclear power generation. In fiscal 2011, the cost of fuel for thermal power as a share of the overall cost of power generation rose to 67%. For the future, based on a clear understanding of energy costs and associated security issues, a calm debate about future energy options is required.

1. Introduction

1-1 Background to research

Triggered by the Fukushima Daiichi nuclear power plant accident in 2011, comparisons of the costs of power generation for a range of power generation methods, including nuclear, thermal (fossil-fuel fired) and renewable power, suddenly started to receive public attention in Japan. On the basis of an assessment by the Subcommittee to Study Costs and Other Issues in 2004 [1], nuclear power had conventionally been regarded as comparing favorably in cost terms with other sources of electricity, although some people, including NGOs [2], argued that nuclear power generation is fairly expensive. Actually, in the United States, with the growing use of low-priced shale gas, projects to build new power plants have been successively delayed or cancelled. When considering future energy policy, especially policy involving options for the power generation mix, the costs of generating electricy are an extremely important factor and it is crucial to have accurate and objective assessments. This is why the Japanese government set up the Cost Review Committee in 2011 to carry out a review of the cost of generating electricty, and to compile the results in a report [3]. The report comprehensively systematizes and assesses the factors relating to the cost of power generation, including coal-fired, natural gas-fired, and oil-fired power generation, nuclear and renewable energy power generation, cogeneration and so on. As a result, the cost of generating electricity with nuclear power is estimated at JPY8.9/kWh “and up,” which compares favorably with JPY9.5-10.3/kWh for coal-fired power generation, or JPY10.7-10.9/kWh for LNG-fired generation, even though the figure depends on assumptions around the amount of damages caused by the Fukushima accident (assumed amount of damages of JPY5.8 trillion would raise the cost of power generation by JPY0.09/kWh for each trillion yen increase).

The estimations of the Cost Review Committee are based on the “model plant method”, where the average cost of power generation for the whole lifecycle of the plant is estimated on the basis of assumptions for a wide range of data, including the

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cost of constructing power plants, personnel costs, repair costs, fuel costs, as well as assumptions about service life and discount rates. In a sense, this is the cost of power generation in an "idealized" situation, and it may differ from the actual one required when power utilities generate electricity. In contrast, it is possible to calculate the actual costs of power generation from the historical data that appear in corporate financial statements of the power utilities. By dividing the cost by the electricity output, we can assess the actual unit costs of nuclear, thermal and hydro power generation. By comparing the cost of power generation based on this method with the cost based on the method of using model plants, it is possible to verify the validity of the latter method. With this method it is possible to assess an actual cost that has small portions to be extracted from the real data, or to be presumed or assumed. It assesses not only the performance of the technology itself, but also the associated social and political factors. These types of assessments are considered useful for the formulation of realistic national energy plans and policies.

Since the method that uses corporate financial statements basically performs assessments that target actual values for a single year, it is difficult to assess the whole of the cost structures associated with long-term construction, amortization and power generation at an actual plant. In particular, this point is often referred to where the costs of hydro and nuclear power generation are concerned. Since most of the hydro plants in Japan today have already completed amortization, the cost of electricity generated by hydropower becomes extremely cheap when estimated with this method. Although we can assess "the cost of hydro when using existing facilities" with this method, we cannot assess the cost including the expenses for dam construction, etc. Similarly, but probably not to the same extent as hydro, most of the nuclear power plants in Japan have already completed or are about to complete amortization, and therefore, with this method, it is necessary to device a way to assess properly the capital unit costs of nuclear power generation (i.e. average capital cost across the whole process from power plant construction start to closure divided by power output).

Oshima [4] used the corporate financial statements of nine power companies from fiscal 1970 to 2007 and by obtaining a long-term average, attempted to assess average power generation unit costs, taking into account the impact of amortization. As described below, however, since Oshima's method is actually influenced by the change in interest rates and price movements, it is impossible to assess "the average cost of power generation" that plays a important part in policymaking. In this study the authors carry out new estimates based on the corporate financial statements over the long term from fiscal 1970 to 2011, and assesses the average cost of power generation for thermal, nuclear and hydro power, eliminating the impact of changes in interest rates and fluctuations in commodities prices. This study also attempts to assess the characteristics of each source of electricity by assessing long-term trends in the classified costs of power generation. In addition, it compares the classified unit cost of power generation with the estimation results of the Cost Review Committee to verify their validity.

2. Methodology

Based on methods that are similar to past studies [5], this study estimates the cost of power generation for hydro, thermal power (steam + internal combustion), nuclear power, and "geothermal, etc." (described as "new energies" in the corporate documents) using the corporate financial statements of power utilities [6, 7]. It calculates the unit cost of power generation by dividing the cost in the relevant fiscal year by the power output. Here, the cost of power generation is the sum of the operating cost at utility operators and the interest expenses listed in the statement of profit and loss. The interest expenses are calculated by apportioning overall interest expenses for the utility according to the ratio of fixed assets plus construction suspense account for each power generation method. As the denominator for the division, we used the amount of electric energy at the supply end(deducting in-house loss [8] from the power output). We used corporate financial statements from fiscal 1970 to 2011 of the nine general power companies in Japan except Okinawa Power Co., for the estimates, from the viewpoint of data continuity.

Since the the financial statements include detailed lists of the operating costs, it is possible to classify costs into several categories. This study has classified the costs according to Table 2-1. The value of the apportioned interest expense is included in "Capital cost."

In terms of expenses and prices, in addition to the nominal prices sought from the corporate financial statements, we calculated the real 2011 values using GDP deflators, and the latter was used when obtaining the average across a time series.

Since fiscal 2009, the item “New energies” has appeared in the corporate financial statements of power companies. The item includes power generation by solar photovoltaics, wind power, geothermal and other renewable energies, but due to aspects of scale, it mainly reflects the cost of geothermal power generation in the estimates for the nine power companies. Consequently, in this paper, these energies are listed as “Geothermal, etc.”

Table 2-1 Classification of power generation costs specified in detailed lists in the financial statements of power utilities

Category	Item Classification
Capital cost	Fixed asset tax, amortization expenses, loss on retirement of fixed assets, contributions for shared facilities, etc.
Fuel cost	Fuel expenses
Back-end cost	Spent fuel reprocessing expenses, spent fuel reprocessing setup expenses, waste disposal expenses, specified radioactive waste disposal expenses
Decommissioning cost	Nuclear power generation facility dismantlement expenses
O&M cost	All other expenses

3. Results and Discussion

3-1 Long-term trends and average costs of power generation by source of electricity

Figure 3-1 presents a breakdown of the power generated by nine general power companies. As shown here, hydro power generation has fluctuated around the 60TWh level in the past, and thermal and nuclear power generation has continued to rise, in line with the rise in demand for electricity. Therefore, the ratio of hydro has declined from 23% in fiscal 1970 to 8% in fiscal 2010. The ratio of thermal power generation has also declined from 76% in fiscal 1970 to the 50-60% level with a significant decline in the 1980s when several nuclear power plants started operations. As a result, the Herfindahl-Hirschman (HH) index[1], which indicates the concentration of power sources, has fallen from 0.64 to 0.46. However, following the suspension of operations at nuclear power plants in 2011, the ratio of thermal power has risen to 79% and accordingly, the HH index has also risen to 0.64.

[1] The HH index was invented to assess market concentration; the higher the value, the greater the concentration, and the lower the value, the more progress toward decentralization. In the case of the three types of hydro, thermal, and nuclear power output, the HH index is obtained by totaling the squares of each market share , with its minimum value 0.33.

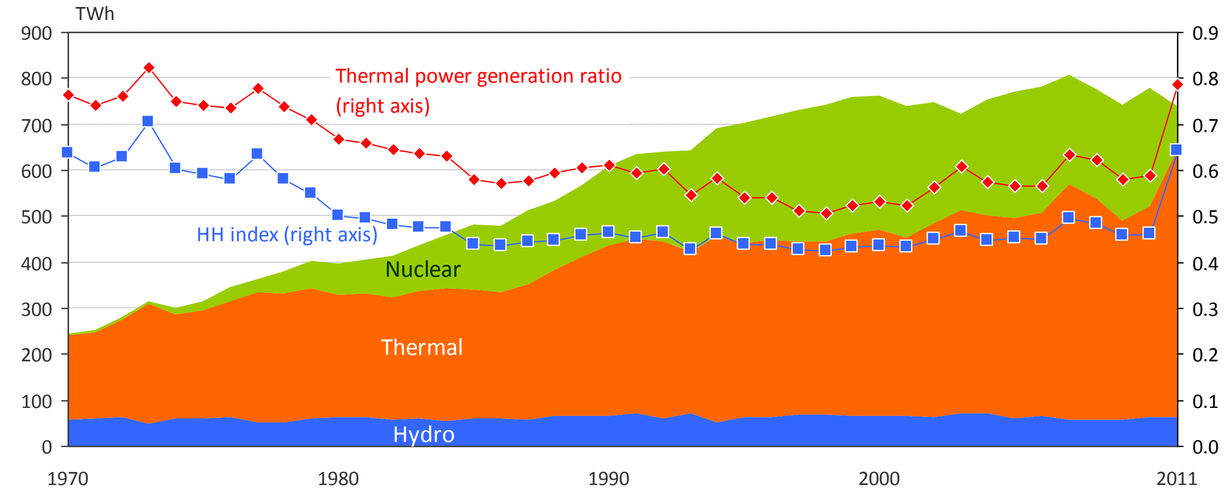


Fig. 3-1 Breakdown of power generation (total for 9 companies)

Figure 3-2 indicates the trends in the average unit cost of power generation (average for all sources of electricity) for the nine companies. The unit cost of power generation (in real terms) fluctuates around JPY7-8/kWh at stable times, but it increased to JPY13.7/kWh in the 1980s when the crude oil prices rose steeply. Since 2005, the cost of power generation has again been going up with the sharp increase in the prices of crude oil to reach JPY11.8/kWh in fiscal 2011. However, compared to the 1980s, the present rise in the cost of power generation is smaller. As will be discussed later, Japan's efforts to diversify energy sources since the 1980s are a major factor here.

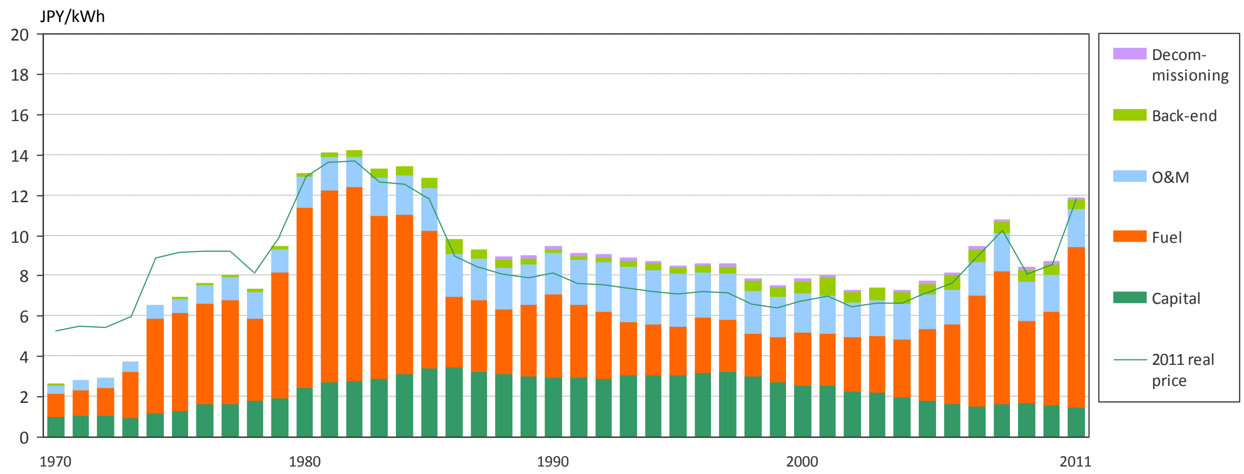


Fig. 3-2 Trends in average power generation unit cost for all electricity sources (FY1970-2011)

Figure 3-3 shows the average unit cost of power generation (average for 9 companies) by source of electricity from fiscal 1970 to 2011. In order from the lowest, the cost is JPY6.2/kWh for hydro, JPY7.0/kWh for nuclear, JPY9.3/kWh for geothermal, etc., and JPY9.3/kWh for thermal. As will be discussed later, the price of hydro is the cheapest because amortization has progressed the furthest by now. For thermal power, the most expensive option, the cost of fuel accounts for as much as 66%, and the steep rise in fossil fuel prices has made thermal power generation expensive.

The JPY7.0/kWh cost of nuclear power generation can be broken down into JPY2.7/kWh in capital cost, JPY0.8/kWh in fuel cost, JPY2.1/kWh in operating and maintenance (O&M) cost, JPY1.1/kWh in back-end cost, and JPY0.2/kWh in decommissioning cost. Compared to thermal power, the capital cost, O&M cost and back-end cost are higher, but the fuel cost is much lower.

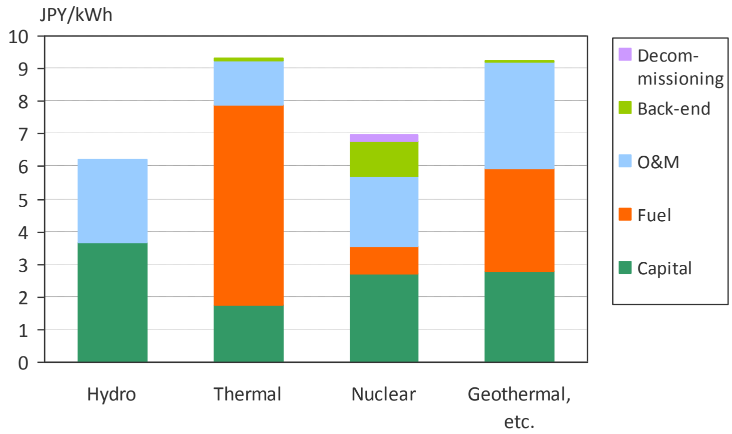


Fig. 3-3 Cost of power generation by source (FY1970-2011 average)

3-2 Power generation costs by source

3-2-1 Nuclear power generation

(1) Long-term trends in power generation unit cost

Figure 3-4 shows the histrical trends in the unit cost of nuclear power generation. For the initial year of fiscal 1970, the unit cost was extremely high because the amount of power generated was very small, but subsequently the real unit cost was stable at around JPY6-10/kWh. The main cause of the increase in nominal unit cost from 1971 to the middle of the 1980s is the increase in commodities prices. The real power generation cost, indicated by the green line in the chart, has on the whole remained level, or been on a downward trend until fiscal 2010.

As the breakdown in the graph indicates, the main reason for the decline in the cost of nuclear power generation is the change in capital cost. The decline in the interest portion of capital cost is particularly remarkable. The decline in capital cost has been subdued since the 2000s, but O&M costs and back-end costs have risen instead compared to the late 1990s. On the whole, the total unit cost is moving in a negative correlation with the capacity factor. In particular, after the Fukushima accident in 2011, the cost has increased to JPY14.1/kWh as a result of the decline in the capacity factor.

As mentioned in Chapter 1, when using corporate financial statements to assess costs, an important issue is how to handle the decline in capital costs associated with the amortization of nuclear power generation. In the following sections the analysis will first focus on the assessment of these capital costs, and then we will also analyze O&M costs and back-end costs.

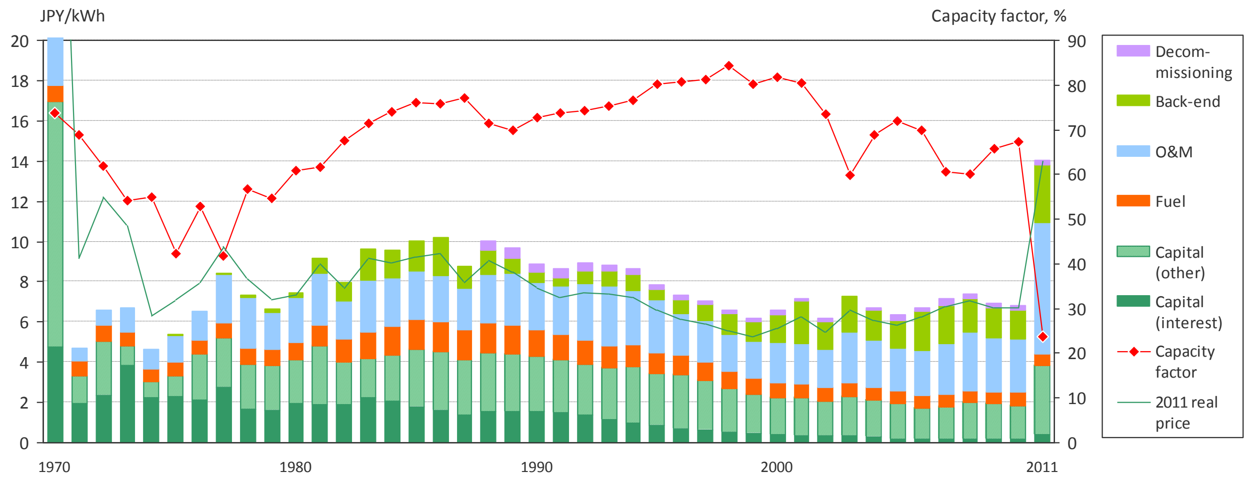


Fig. 3-4 Trends in nuclear power generation unit cost (FY 1970-2011)

(2) Impact of interest rates on capital cost

As indicated in Figure 3-4, the capital cost of nuclear power generation has continued to decline since 1990. Capital cost consists of interest expenses and other costs (amortization expenses, removal cost, etc.). We can read from the graph that both of them had been falling. Changes in interest rates are supposed to have had a significant impact on the interest expense.

Figure 3-5 presents the total amount of interest expenses and the balance of interest-bearing debt (both in nominal terms) at the nine power companies, together with the Japanese long-term prime rate [9]. We can see from the chart that interest-bearing debt rose until the 1980s as construction of new power plants progressed, and as a result, interest expenses also increased. However, when interest-bearing debt took a downward turn at the start of the 2000s, there was even more momentum behind the decrease in interest expenses, which concurs with the decline in interest rates. In actual fact, the value of interest expense divided by the balance of interest-bearing debt indicated by the blue line in the graph, i.e., the average interest rate for the utilities, declined similarly to the long-term prime rate, from just under 7% in the 1970s to 1.5% in 2011 (since the interest-bearing debt of the utilities includes not only long-term loans, but also corporate bonds and short-term debt, the blue line does not agree exactly with the long-term prime rate indicated in orange). That is, for argument's sake, if the current low interest rates had applied in the past, the interest expense amount would have been far smaller than the one shown in Figure 3-5.

In Figure 3-6, the interest expenses of nuclear power regeneration are shown as "before correction." If we remove the effect of the interest rate changes by dividing the expenses by the average interst rate (solid blue line in the Figure 3-5) normalized as 1 for the figure in 2011 (1.5%), we get the trends in interest expenses shown as "after correction" in Figure 3-6. In contrast to the JPY0.73/kWh contribution (1970-2011 weighted average, real value) to the cost of power generation "before correction," our calculations use the values "after correction" to indicate a contribution of JPY0.22/kWh, and the difference (JPY0.52/kWh) can be regarded as the impact of the interest rate changes on the average cost of nuclear power generation.

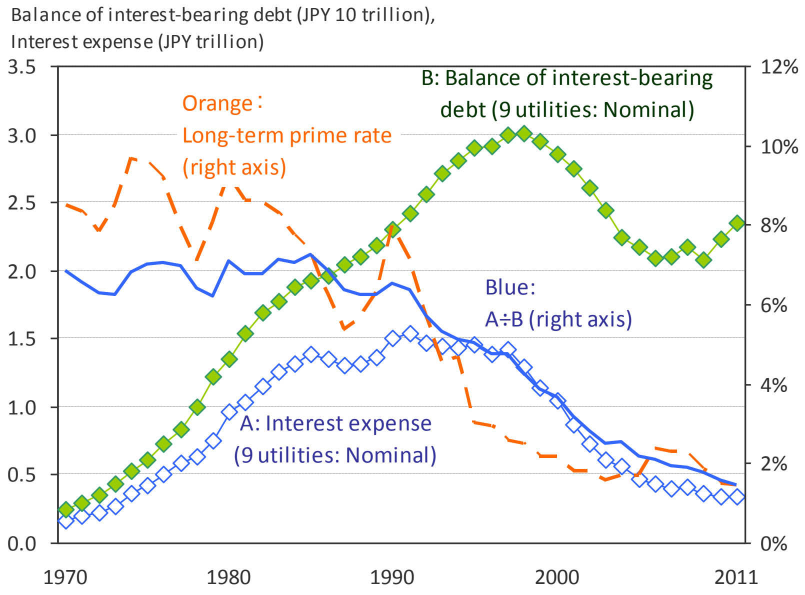


Fig. 3-5 Interest expenses and balance of interest-bearing debt (total of 9 companies), and long-term prime rates

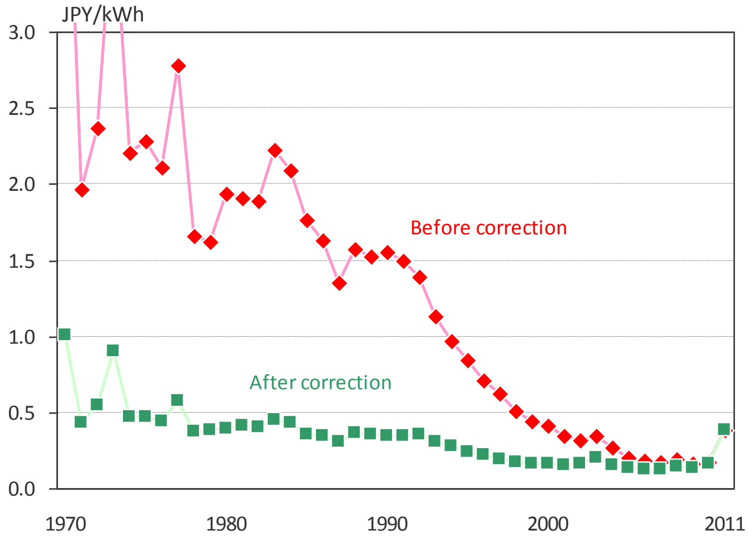


Fig. 3-6 Interest expense contribution to the nuclear unit cost (in nominal terms)

Existing nuclear power plants include not only the ones that have operated for thirty years or more, but also ones that have started operating fairly recently. Therefore, we must bear in mind that averaging capital cost from fiscal 1970 to the present, generally, assesses the cost of nuclear power generation higher than the actual average cost across the total years of operation. The same is true for hydro power as described below.

(3) Back-end and O&M costs

Figure 3-7 shows trends in back-end cost and O&M costs (in real terms). Here, the back-end cost refers to the aggregated back-end-related costs listed in the corporate financial statements. Specifically, the cost of decommissioning nuclear power plants, the spent fuel reprocessing costs and setup costs, and the specified radioactive waste disposal costs are included.

After rising to a high of JPY1.8/kWh in the 1980s, back-end costs dropped to JPY1.0/kWh or below in 1990s, and then they have been rising again since 2000. O&M costs, on the other hand, have remained stable at around JPY2.0/kWh with the exception of fiscal 1970 at the initial period, and fiscal 2011 when the capacity factor dropped significantly.

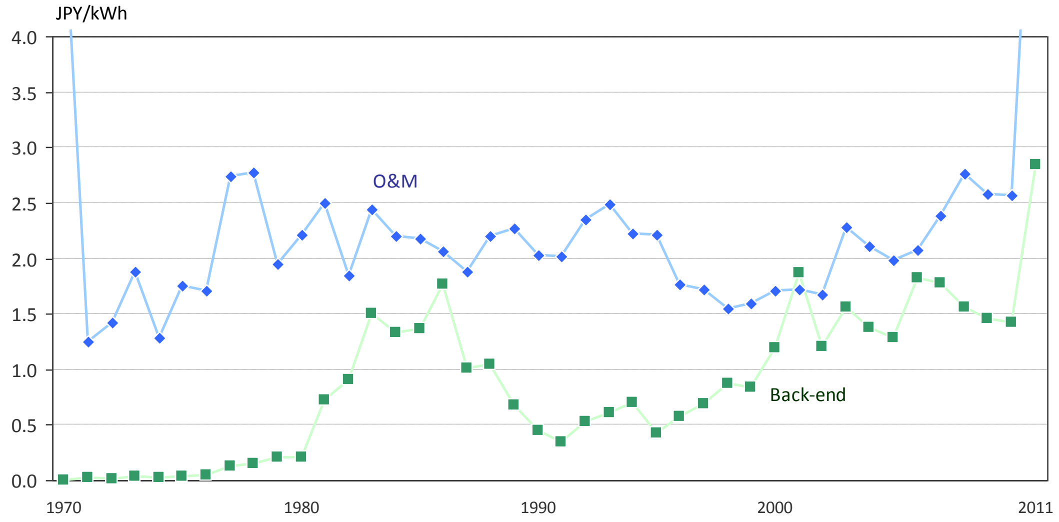


Fig. 3-7 Back-end and O&M costs for nuclear power generation (in real terms)

Back-end costs rose in the 1980s, because the cost of reprocessing spent fuel, which has been calculated as the necessary costs for the future construction and operation of the Rokkasho reprocessing plant, began to be funded from 1981. Later, as the upper limit for the funds was gradually reduced to 60% of the total estimates of the reprocessing costs in the period up to 1997, and the cost of reprocessing was temporarily overfunded, the cost of reprocessing was not added up during the period from the late 1980s to the late 1990s, resulting in a decrease in back-end costs. But in 2005, changes were made to the legal system of reserves for back-end costs, and since then, the reserves for the portion of power generated before 2005 began to be added up to the back-end costs. This is why back-end costs reach a fairly high level in the late 2000s.

(4) Fuel cost

Figure 3-8 shows the trends in fuel costs. As indicated here, fuel costs have been decreasing since the second half of the 1980s. The fluctuating exchange rates have been a major factor of them, and if the exchange rate is deducted (green line in the chart), costs have remained fairly stable since 2000. Even though the fuel cost is roughly 0.5 US cent/kWh, it rises to a maximum of 1.0 cent/kWh from the late 1980s to the 1990s. This is probably due to the sharp rise in nuclear fuel prices (including the costs of conversion, enrichment and other processes) because of the massive construction of nuclear power plants worldwide from the late 1970s to the 1980s.

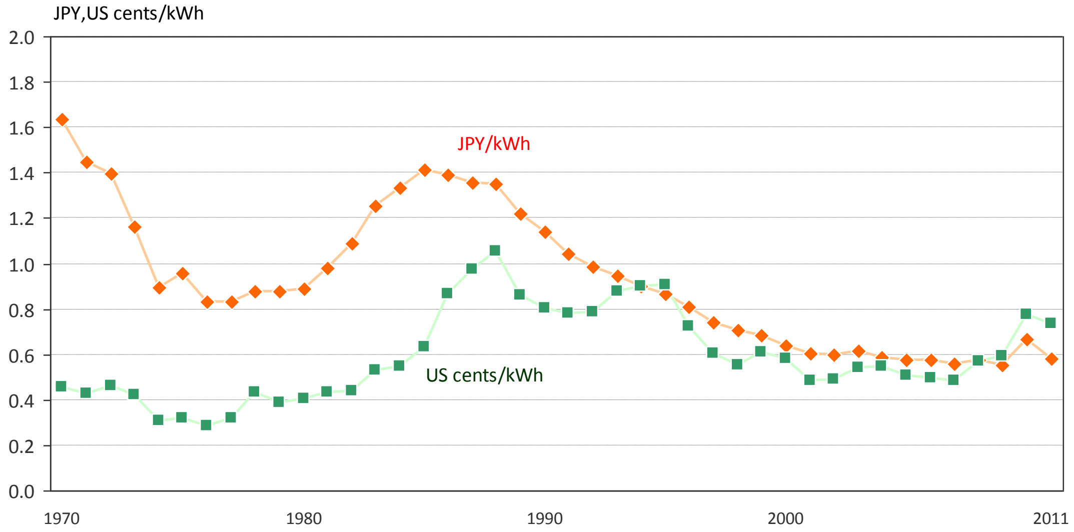


Fig. 3-8 Trends in fuel cost for nuclear power generation (in real terms)

3-2-2 Thermal power generation

(1) Long-term trends in the cost of power generation

Figure 3-9 shows the trends in the cost of thermal power generation. As indicated here, the cost of thermal power generation fluctuates greatly because it is directly linked with the CIF price of imports of crude oil [10]. In particular, the cost of power generation rose significantly in the first half of the 1980s and after 2005 when oil prices went up. Compared to the first half of the 1980s, however, there has been a relatively small rise in the cost of power generation since 2005 when the crude oil prices rose sharply. As described below, this can be viewed as the effect of fuel diversification. In fiscal 2008 and 2011 when crude oil prices rose steeply, the cost of power generation (in real terms) rose to JPY12.3/kWh and JPY12.1/kWh, respectively.

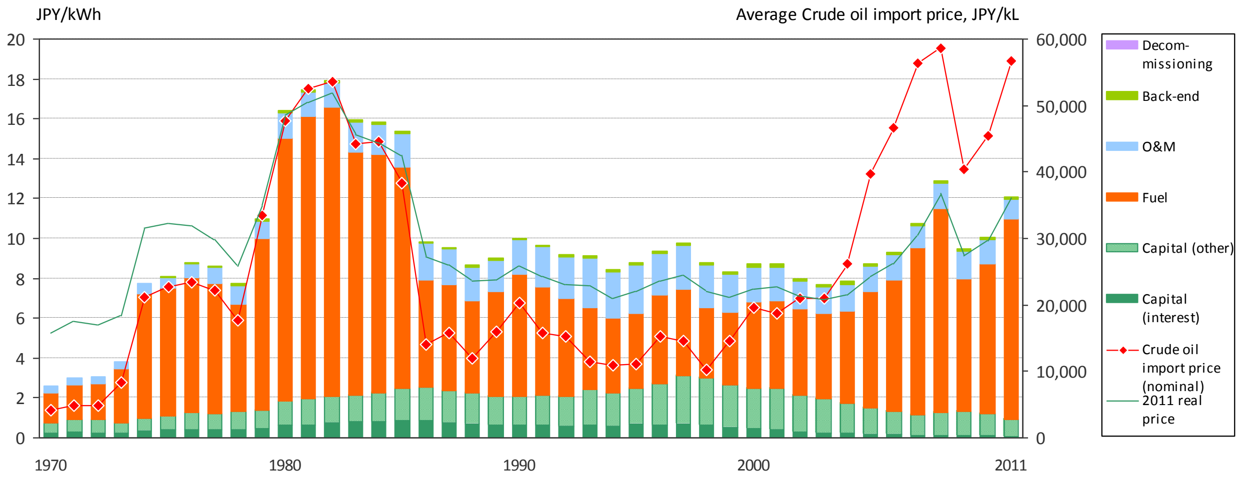


Fig. 3-9 Trends in the cost of thermal power generation (FY1970-2011)

(2) Share of fuel cost in the cost of power generation

Figure 3-10 shows the share of fuel cost in the cost of thermal (fossil-fuel fired) power generation, and the share of thermal fuel cost in total power generation cost. Fuel costs as a share of thermal power rose to 80% in the 1980s when the price of crude oil rose sharply, but with the decline in crude oil prices, the share declined to 40-50% in the 1990s. Then at the start of the 2000s, the share again rose with the increase in fossil fuel prices, reaching 83% by fiscal 2011. Since the cost of fuel for thermal power generation is directly impacted by the changes in exchange rates and in the import prices for primary energy, the excessive reliance on thermal power generation makes the nation's energy security extremely fragile.

The share of thermal fuel cost in the total cost of power generation was over 60% in the early 1980s, but dropped to 20-30% in the 1990s. However, with the steep rise in fossil fuel prices since 2005, the share is again rising above the 50% level, reaching 67% in fiscal 2011 when the operations of the nuclear power plants were suspended. These are strong grounds for requiring a cheap and stable supply of fossil fuel.

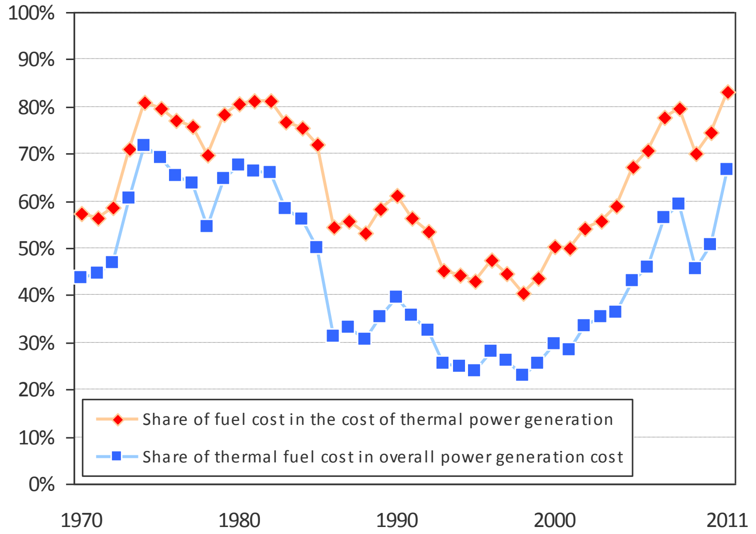


Fig. 3-10 Trends in the share of thermal fuel cost in thermal power generation cost and total power generation cost

3-2-3 Hydropower

(1) Long-term trends in power generation cost

Figure 3-11 shows the trends in the unit cost of hydropower generation, and Figure 3-12 shows the year when the existing hydropower plants started operation [11]. As shown here, most of the existing hydropower plants, in particular, "general" hydropower plants (i.e. other than pumped-hydro), started operations before 1970. Taking into account amortization and the changes in the commodities prices, it is conceivable that the initial construction costs of these power plants have only a small impact on the cost of power generation after 1970s. Reflecting this, the cost of hydropower generation at roughly JPY6-8/kWh is, on the whole, lower than thermal or nuclear. Even so, when averaging the whole, the ratio of capital cost in the cost of power generation is 59%, which is higher than other power generation methods. Since the late 1980s, the cost contribution of the interest expense has decreased, reflecting the decline in interest rates, and accordingly, the overall cost of power generation has been decreasing.

The real cost of hydro reached its highest level of JPY9.2/kWh in fiscal 1994, coinciding with a time when one large-scale pumped-hydro power plant after another started operations, including the TEPCO Shiobara power plant (900MW, started operations in 1994), the Chubu Electric Okumino power plant (1.5GW, started operations in 1994-95), and the KEPCO Okochi power plant (1.28GW, started operations in 1992), suggesting that the construction of large-scale facilities had a substantial impact on the average hydropower generation cost.

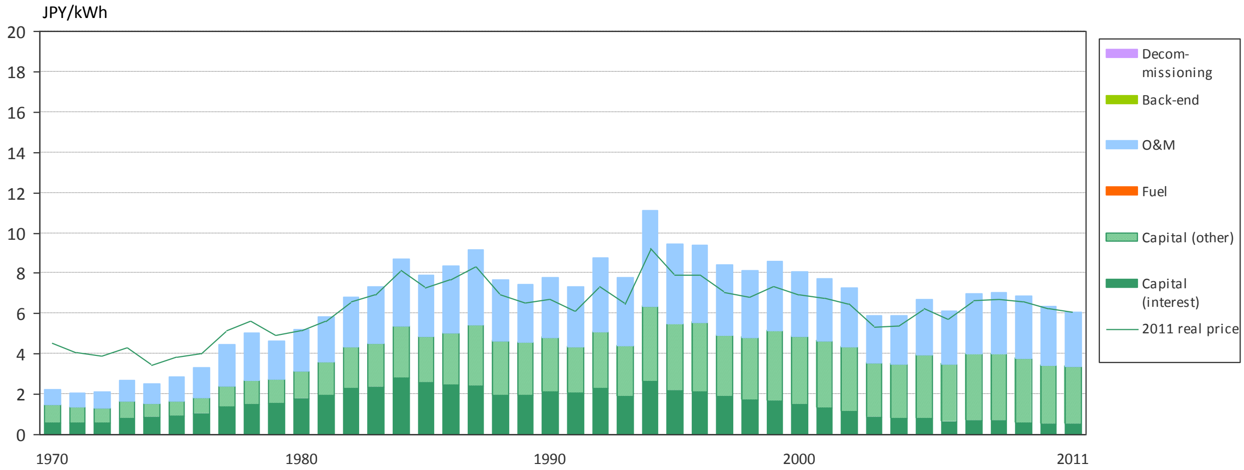


Fig. 3-11 Trends in hydro power generation unit cost (FY1970-2011)

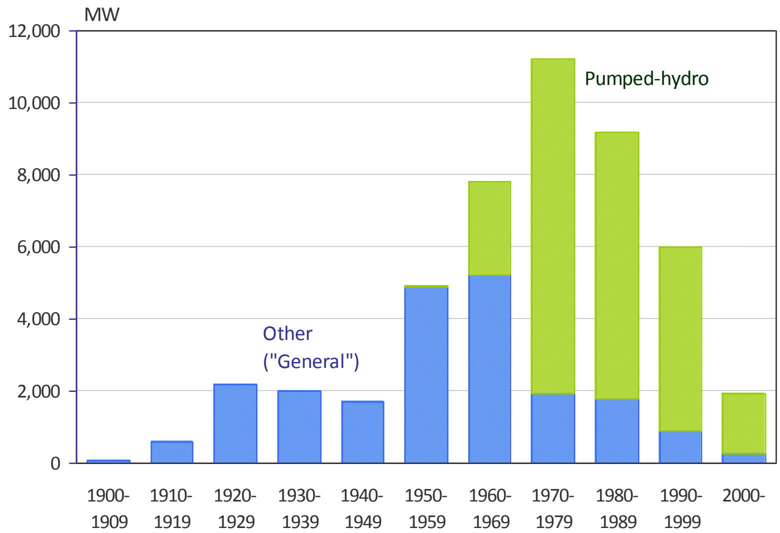


Fig. 3-12 Years of launching hydropower plants

(2) Impact of amortization

As mentioned above, since a large number of the hydropower plants in Japan have already completed amortization, the hydropower generation unit costs estimated based on corporate financial statements are characteristically low. In this section, we attempt to assess the cost of power generation at the power plants that started operations in 1970 or later in order to assess the total hydro cost, including the costs associated with construction. The process is as follows:

(1) Based on data on the year when existing hydropwer plants started operations [11], classify the hydropower plants for each fiscal year into those that started operations before and after fiscal 1970.

(2) Based on the total hydropower output and the power generating capacity for each classification (before and after 1970), estimate the respective power output, assuming that the average capacity factor is the same for the plants before and after 1970.

(3) All fixed assets at the hydropower facilities in 1970 are treated as the fixed assets of "before 1970," and depreciated in step with amortization in fiscal 1971 and later. These are deducted from the total fixed assets of hydropower facilities, and the remainder is regarded as the fixed assets of "after 1970." The cost of amortization is proportionate to the fixed assets in the

relevant fiscal year, and divided proportionally between the earlier/later start of operations.

(4) Other capital cost including interest expenses are also divided proportionally in the same way as the amortization cost. O&M costs are divided in proportion to the power generating capacities.

Figure 3-13 shows the result of the estimates. While the total unit cost of hydropower is largely at the JPY5-10/kWh level, the facilities that started operation in and after fiscal 1970 are remarkably expensive at JPY15-20/kWh. This should be consulted for the real value of the cost of hydropower generation, including the construction costs. It must be noted, however, that similarly to nuclear power, there are still many unamortized facilities so that the estimates for the past forty years tend to be on the high side for capital cost. In particular, since there are many cases of hydropower plants operating for longer than forty years, we assume that the cost is actually midway between JPY6.2/kWh and JPY15.3/kWh in Figure 3-13.

Here, the hydropower generation cost (operations started in and after 1970) includes both pumped-hydro and other ("general") hydro. Generally speaking, for pumped-hydro power generation, the power output is small in proportion to the scale of the facilities, and therefore, we may suppose that the cost of general hydro aside from pumped-hydro is somewhat lower than the total unit costs. Accurate assessments, however, are an issue for future work.

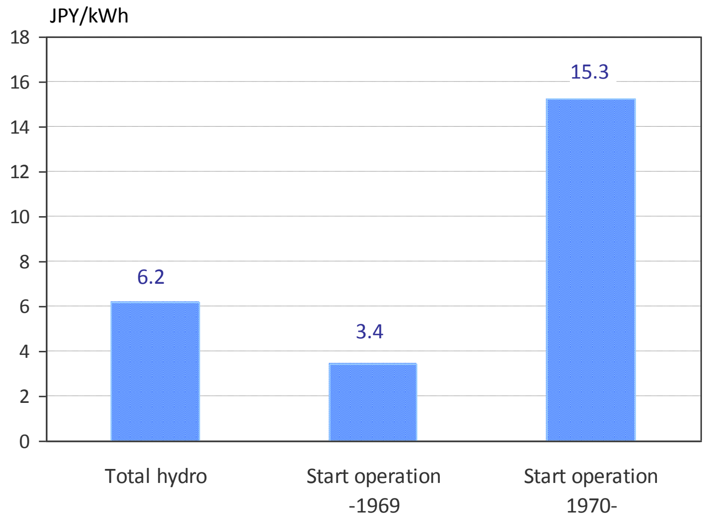
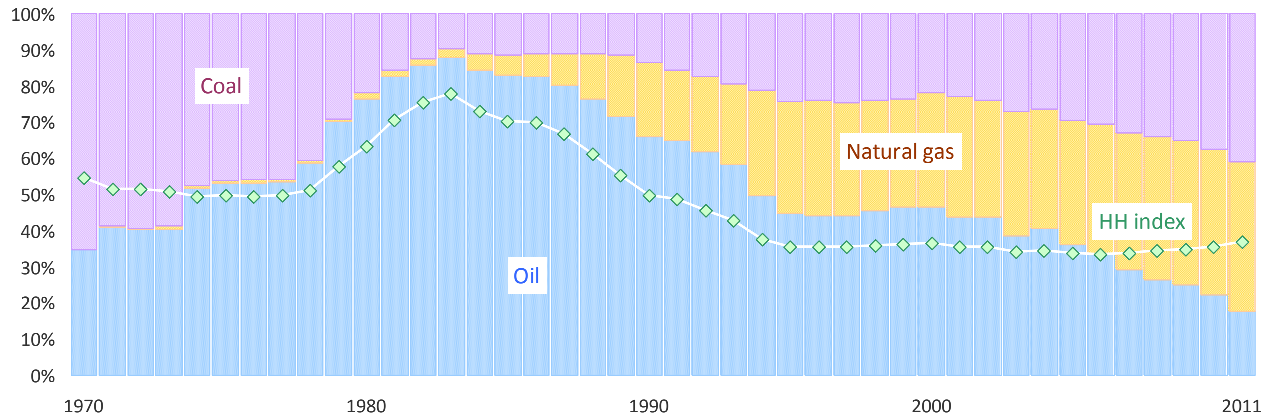


Fig. 3-13 Cost of hydropower generation (FY1970-2011 average)

3-2-4 Diversification of the sources of power generation and dealing with the risk of steep rises in fossil fuel prices

In the time between the oil crises in 1970s and the Fukushima Daiichi nuclear power plant accident, a major pillar of Japan's energy policy has been to aim to mitigate risk by diversifying the energy supply. As shown in Figure 3-1, the result has been advanced diversification among hydro, thermal, and nuclear power, as well as diversification within thermal power generation. Figure 3-14 indicates the share of coal-fired, oil-fired and natural gas-fired power generation in total thermal power generation in Japan [12] (this chart shows the share in total thermal power generation in Japan, which is slightly different from that for the nine general power companies analyzed in this report). As indicated here, oil-fired accounted for 70-80% or more in the 1980s, but since then the introduction of natural gas-fired and the growing use of coal-fired have brought the HH index down from a high of 0.78 in 1983 to 0.35 in 2010.



Source: IEA, "Energy Balances of OECD countries"

Fig. 3-14 Share of oil-fired, coal-fired and natural gas-fired power in thermal power generation

In this way, the diversification of sources of generating power has made headway in a double sense, and as shown in Figure 3-15, we can see that the rise in the cost of power generation (thermal power generation and total power generation) when prices rose steeply in the second half of the 2000s has been remarkably small compared to early 1980s.

Concerning the period of fiscal 1979-1985 when oil prices rose steeply (previous price rise), and the period since fiscal 2005 when prices have again risen steeply (current price rise), Figure 3-16 shows the elasticity of the unit cost of generating electricity (thermal power generation and total average for power generation) wirh respect to the rise in crude oil prices from the period before the rise (fiscal 1970-72 and fiscal 1990-2003, respectively). As indicated here, the elasticity, which was 0.44 (thermal) and 0.34 (total average) at the previous steep price rise, has now decreased to 0.12 and 0.08, respectively. This is to say that the diversification of sources of power generation and the shift from oil-fired to coal-fired and natural gas-fired power generation of which the fuels are cheaper have contributed significantly to improved energy security. In this comparison, the elasticity of the unit cost of power generatin (total average) with respect to the cost of thermal power generation has also decreased from 0.77 to 0.66, suggesting that the diversification among thermal, nuclear and hydro power has also contributed to the stability of the cost of power generation together with the diversification and shift within thermal power generation.

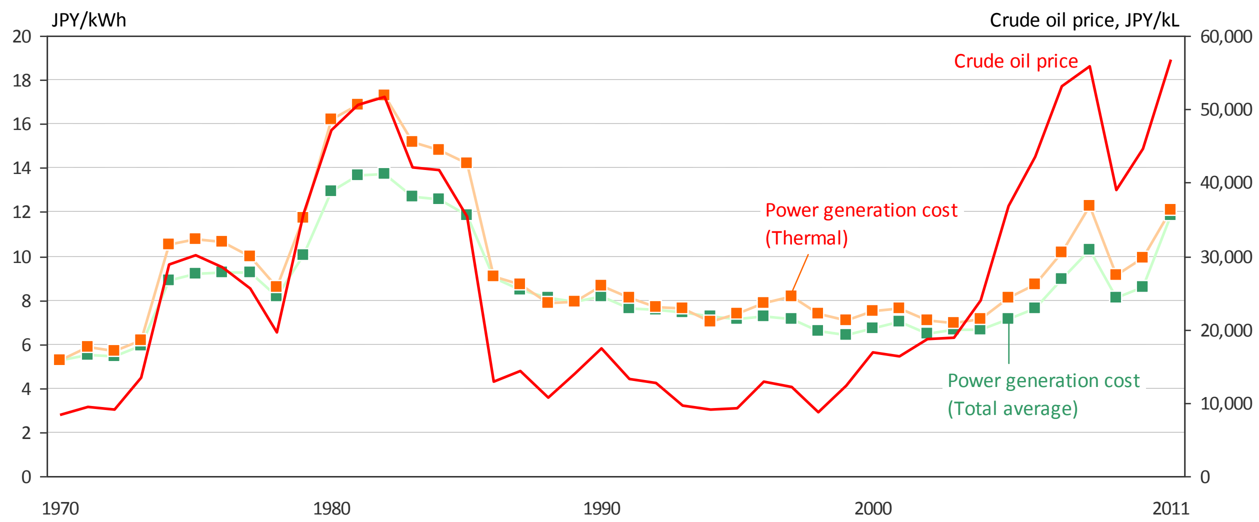


Fig. 3-15 Trends in oil price and power generation cost (thermal and total average) (in real terms)

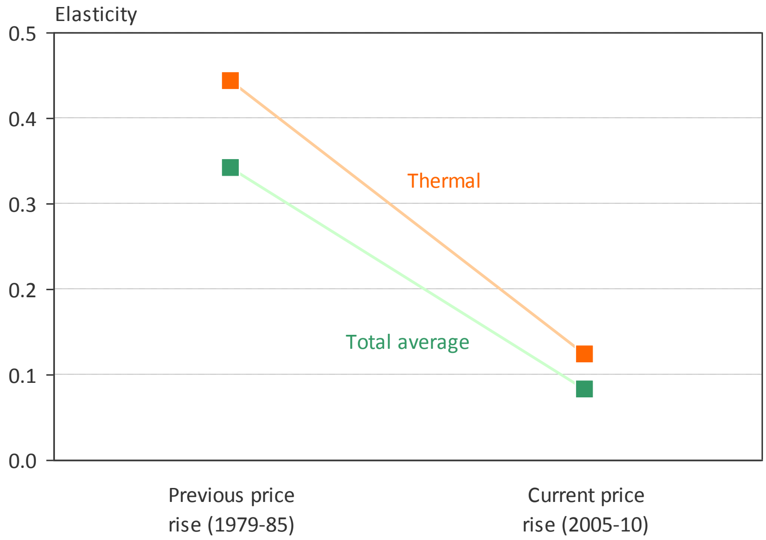


Fig. 3-16 Elasticity of the cost of power generation against rising oil prices

3-3 Comparison with other estimation results

3-3-1 Comparison with the "model plant" method

The 2011 Cost Review Committee carried out a detailed examination of power generation costs in Japan [3]. The OECD estimation [13] is another report widely cited worldwide, which assesses the power generation costs for a range of sources of electricity generation for Japan and other countries. Both reports are based on the model plant method. In this section, we compare these estimations with the results of the calculations in this study. The OECD estimations present two cases at discount rates of 5% and 10%, and the 5% case is presented below.

Estimation by the Cost Review Committee differs significantly from other assessments on the point of "the policy cost, etc.", which is recorded as JPY1.6/kWh and up. The amount includes "policy expenses" and "accident costs." The former expense includes subsidies for siting, as well as research and development (R&D) costs (includes R&D for advanced technologies such as fast-breeder reactors in addition to R&D for operating light-water reactors) based on the national budget for fiscal 2011, with costs estimated at JPY1.1/kWh. The latter expense provisionally assumes that damages caused by the Fukushima accident to JPY5.8 trillion and up. By dividing this amount by the total nuclear power output in Japan over a period of 40 years, the contribution to the cost of power generation is estimated at JPY0.5/kWh and up.

Figure 3-17 compares the costs of nuclear power generation. As indicated here, there is a large gap between the OECD estimation of JPY5.1/kWh and the Cost Review Committee's estimation of JPY8.9/kWh and up. Even if the abovementioned policy costs, etc. are excluded, the difference is still JPY2.1/kWh. The difference is largely due to variations in O&M cost (JPY1.7/kWh and JPY3.3/kWh).

The results of this study (average for fiscal 1970-2011) indicate that the cost of nuclear power generation (after correction for interest rate impact) is JPY6.4/KWh, which is slightly smaller than the figure from the Cost Review Committee (discount rate 3%) after deducting policy costs, etc. (JPY7.3/kWh). As mentioned above, the OECD estimation assumes a higher discount rate of 5%. Taking into account the fact that lowering the discount rate would further depress the cost of power generation, we recognize, on the basis of the assessment of actual past values carried out in this study, that the results from the Cost Review Committee are closer to the actual costs than the OECD estimation.

Breaking down and comparing the costs in the estimation by the Cost Review Committee with the results of this study indicates that fuel costs are almost the same (both JPY0.8/kWh), capital costs (JPY2.5/kWh and JPY2.2/kWh after interest rate correction) are slightly lower for the latter. At the same time, there are big differences in O&M costs (JPY3.3/kWh and JPY2.1/kWh, respectively) and back-end costs (JPY0.5/kWh and JPY1.1/kWh, respectively).

As far as back-end costs are concerned, the Cost Review Committee assumes the "current model" (half of the spent fuel is reprocessed and recycled for use, and half is stored for an interim term of 50 years for later use) based on the estimation of the Atomic Energy Commission [14], and assesses the cost at JPY0.5/kWh. However, this is reduced to JPY0.2/kWh for the "direct disposal model" (spent fuel is not reprocessed, but directly sent to underground repositories), while it increases to JPY1.1/kWh for the "reprocessing model" (spent fuel is not stored for the interim term, but immediately reprocessed). The big difference between the current model and the reprocessing model is that the cost of reprocessing half of the spent fuel is heavily discounted at a discount rate of 3% due to the interim 50-year storage, which is the reason for the extremely cheap price.

At the time of the actual reserves, the costs were added up without assuming interim storage, which suggests that back-end costs are close to the abovementioned "current model." In any event, we understand from these observations that back-end costs may vary significantly depending on reprocessing and interim storage options.

Table 3-1 presents a breakdown of O&M costs. Based on the average values for the plants sampled by the Cost Review Committee (Tohoku Electric Power Co., Higashidori unit 1, Chubu Electric Power Co., Hamaoka unit 5, Hokuriku Electric Power Co., Shika unit 2 and Hokkaido Electric Power Co., Tomari unit 3), the breakdown of annual costs are assumed to be JPY2.37 billion per unit for personnel costs, 2.2% of the construction cost for repair costs, 1.9% of the construction cost for various costs, and 13.4% of direct costs for general management costs. As Table 3-1 shows, the results of this study, i.e., actual past values, are lower than the Cost Review Committee's figures for personnel costs, repair costs and various costs included in O&M costs. For various costs, the difference is as much as JPY0.55/kWh. The reasons for the difference are unclear, but the Cost Review Committee's figures are the average values for the plants sampled, and since the operators of these plants have relatively few nuclear power generation facilities, it is possible that the various costs have been exaggerated compared to the average for all nine power companies. The general management costs were not included in the authors' estimation, which would produce a difference of about JPY0.4/kWh.

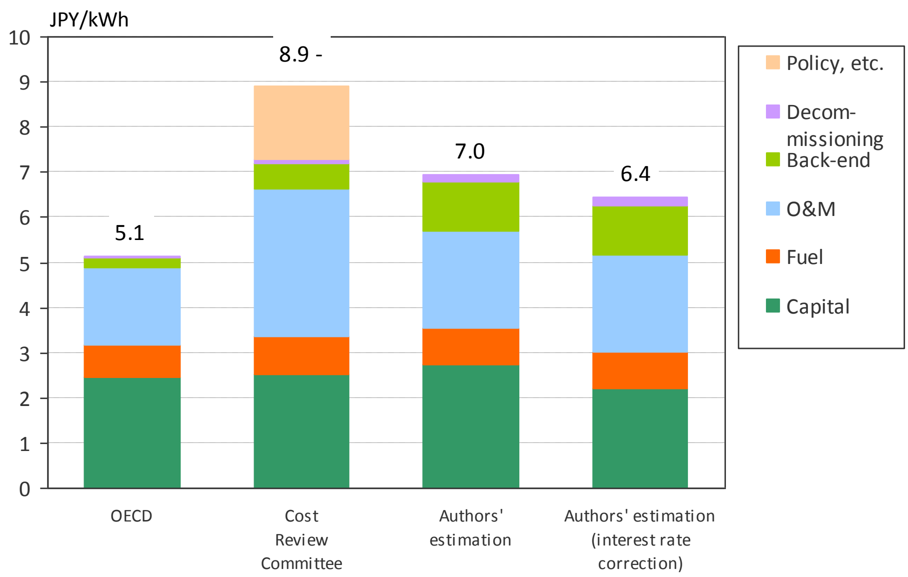


Fig. 3-17 Comparison of nuclear power generation costs

Table 3-1 Comparison of O&M costs (nuclear power)

		JPY/kWh
	CRC	Current study
Personnel costs	0.34	0.30
Repair costs	1.37	1.21
Other various costs	1.18	0.64
General management costs	0.39	-
Total O&M	3.27	2.14

Figure 3-18 compares the cost of thermal power generation. The OECD estimation for coal-fired power generation is JPY9.1/kWh while the Cost Review Committee's estimation is JPY9.5/kWh. For natural gas-fired (LNG-fired) power geneartion, there is little difference between the two estimations at JPY10.9/kWh and JPY10.7/kWh, respectively. On the other hand, for the cost of oil-fired power generation, the Cost Review Committee gives an extremely high estimation at JPY22.2/kWh in 2010 (The Committee report presents two cases with a 10% and 50% capacity factor for oil-fired power generation, of which Figure 3-18 presents the 50% case. If the capacity factor is 10%, the cost of power generation increases to JPY36/kWh). In addition to an assumed crude oil import CIF price that is higher than coal-fired and LNG-fired power in terms of calorific value, the low assumptions for thermal efficiency (on a higher calorific value basis, coal-fired is 42% and LNG-fired is 51% as opposed to 39% for oil-fired) and the low assumptions for capacity factor are the causes for the estimated high costs. Although fuel costs account for a large share of thermal power generation costs and thermal power generation costs depend greatly on assumptions on fuel prices, the authors' estimation is on the whole consistent with the OECD and the Cost Review Committee's estimations for thermal power generation cost, except for carbon prices assumptions.

Table 3-2 presents a comparison of O&M costs for thermal power generation. The estimation by the Cost Review Committee stands at JPY1.3/kWh for coal-fired, JPY0.7/kWh for LNG-fired and JPY1.6/kWh for oil-fired power generation whereas the current estimation (average for thermal power) is JPY1.3/kWh. This shows that actual past values are at a level cosisitent with the Cost Review Committee's estimation on the whole. Since O&M costs vary greatly depending on capacity factors, for an accurate comparison, it is necessary to undertake detailed studies using past data on capacity factors for thermal power generation.

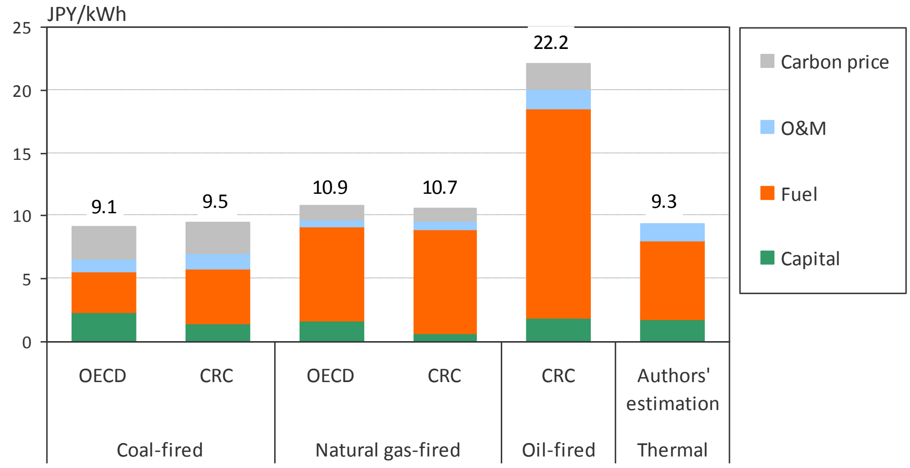


Fig. 3-18 Comparison of thermal power generation costs

Table 3-2: Comparison of O&M costs (thermal power)

JPY/kWh

	CRC			Current
	Coal-fired	Gas-fired	Oil-fired	study
Personnel costs	0.08	0.08	0.13	0.26
Repair costs	0.52	0.35	0.77	0.75
Other various costs	0.52	0.16	0.55	0.34
General management costs	0.16	0.09	0.15	-
Total O&M	1.29	0.67	1.60	1.34

Figure 3-19 presents a comparison of hydropower generation costs. Both the OECD's and the Cost Review Committee's estimations indicate the costs for large-scale hydro, but noticeably, the former is JPY15.8/kWh whereas the latter is fairly cheap at JPY10.6/kWh. In terms of construction unit price (overnight cost) for hydropower plants, the OECD's estimation is JPY870,000/kW, which is nearly the same as the Cost Review Committee's estimation of JPY850,000/kW. The variation in the results is due to differences in discount rates, years of operation, and calculation methods.

The discount rate for the OECD estimation (JPY15.8/kWh) is 5%. If we recalculate the cost following OECD's method using the same 3% rate as the Cost Review Committee, the cost will decrease by approximately JPY4.3/kWh. The OECD used 80 years as the number of years in operation, but if this is changed to the 40 years used by the Cost Review Committee, the cost increases by roughly JPY2.0/kWh. If the OECD's estimation is recalculated with a 3% discount rate and 40 years of operation, the cost of large-scale hydropower is approximately JPY13.5/kWh.

OECD's estimations are calculated on the basis of Levelized Cost of Electricity (LCOE) method where capital cost is calculated by using a prescribed discount rate to convert actual costs over the years required to construct the facilities into present value at the start of operations, and then dividing the total by the total amount of "discounted" power generation over the period of operation. The Cost Review Committee's calculation Excel worksheet, which can be downloaded from the website of the Committee, differs from this in that it calculates accounting amortization costs over a prescribed period of amortization (say, 16 years for nuclear power and 40 years for hydro) instead of calculating the actual cost of plant construction. Moreover, the amortization costs for each year are "discounted" and then summed up, and the total is divided by the total amount of discounted power generation. To get the same result as the general LCOE method used for the OECD's estimation, it would be necessary to assume that the amortization cost was spent at initial construction, and to sum up without discounting. Since the method of estimation used by the Cost Review Committee, however, applied the discount for some reason or other, the estimated costs of power generation become lower. The impact is particularly striking for hydro and other renewable energies, where the share of capital cost in total unit cost is relatively high and the amortization life is relatively long compared with other power generating methods.

If we use the Cost Review Committee's Excel sheet and do the calculation without discounting the cost of amortization as described above, and with the same discount rate of 3% and 40 years of operation, the cost of hydropower generation increases from JPY10.6/kWh to JPY13.5/kWh, producing a result that is at a similar level to the OECD's estimation.

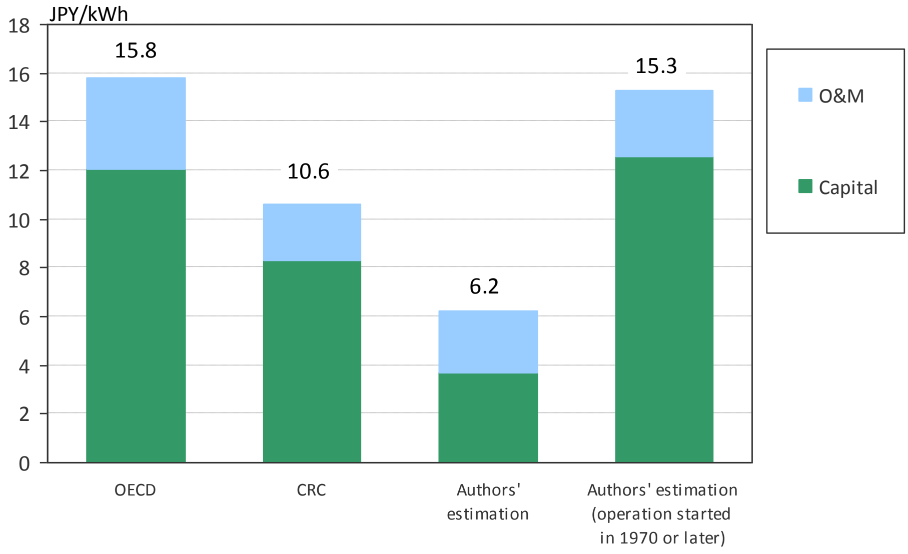


Fig. 3-19 Comparison of hydro cost

In contrast to the results of cost estimation based on the model plant method, the authors' estimation finds that the average cost of hydropower over a period of 42 years is JPY6.2/kWh overall, and JPY15.3/kWh for plants that started operations in fiscal 1970 or later. The latter cost of hydropower generation is slightly higher than the abovementioned estimates based on the LCOE method (discount rate 3%; JPY13.5/kWh at 40 years of operation, JPY11.5/kWh at 80 years of operation). The difference can be explained by the fact that, as mentioned above, the authors' estimation include both pumped and general hydro, and calculate costs only for 40 years or fewer after the start of operations. For a more detailed comparison, however, we would need to separate pumped-hydro and general hydro before assessment.

3-3-2 Comparison with past studies using corporate financial statements

(1) Comparison with previous estimation

In the previous paper [5], the authors carried out assessments using corporate financial statements for a five-year period from fiscal 2006 to 2010, obtaining average results of JPY6.5/kWh for hydro, JPY10.1/kWh for thermal, JPY7.2/kWh for nuclear and JPY9.0/kWh for geothermal, etc. (new energies). Figure 3-20 presents a comparison of the average for this five-year period (2006-2010) and the average for 42 years (1970-2011) of this study. We need to bear in mind that the former targets twelve power companies including wholesale utility operators, while the latter targets nine general power companies.

Compared to the five-year average, there is a significant increase in average capital cost over the 42-year period from JPY1.9/kWh to JPY2.7/kWh for nuclear power generation. Part of the difference is due to the impact of interest rates (JPY0.5/kWh) outlined in Section 3-2-1, and the remaining JPY0.3/kWh is mainly due to the impact of amortization (since the assessment of the five-year average was done at a time when amortization had progressed, capital costs are estimated to be lower than those for the 42-year average).The fuel cost for the 42-year average is slightly higher at JPY0.8/kWh than that for five-year average at the JPY0.6/kWh, due to the impact of rising fuel costs from the late 1980s to the 1990s.

Meanwhile, the average for the 42-year period is lower for both O&M costs (JPY2.6/kWh for five-year average and JPY2.1/kWh for 42-years average), and back-end costs (JPY1.8/kWh and JPY1.1/kWh, likewise). If we break down the variation in O&M costs, the difference in estimation targets (the five-year average in the previous calculation included Okinawa Electric Power Co. and J-Power) and the difference in personnel costs and various costs are JPY0.1/kWh, while the difference for repair costs is JPY0.2/kWh. As mentioned in Section 3-2-1 (3), the difference in back-end costs is due to the addition of the cost of earlier power generation to the fiscal 2006-2010 costs. It is conceivable that the average back-end cost is close to JPY1.1/kWh.

With the method that uses corporate financial statements, the situation varies significantly depending on the targeted year and other conditions. When this method is used, therefore, we also need to study the background after looking at the trends of each component of the power generation costs. Unless appropriate methods are adopted for the estimation according to the purpose of use, it is not possible to obtain valid results. For example, as mentioned in the previous sections, to make a comparison with the estimated costs based on the model plant method, it is necessary to remove the impact of interest rate fluctuations.

Concerning thermal power, fuel costs average JPY7.4/kWh for the five-year period and JPY6.2/kWh for the 42-year period with the latter being somewhat cheaper. The reason is that the estimation for the former is for the period since fiscal 2005 when fossil fuel prices rose rapidly. On the other hand, capital costs are JPY1.3/kWh for the five-year period average as opposed to JPY1.7/kWh for the 42-year period average. As a reason for the higher value for the latter case, it is conceivable that, similarly to nuclear power, interest rates and amortization had an impact (the impact of interest rates and amortization are estimated at about JPY0.3/kWh each) in addition to the differences in the estimation targets (i.e. Okinawa Electric Power Co. and J-Power are included in the previous calculation). The results for hydropower are at about the same level for both periods, showing that the estimated costs are those in a situation where amortization is already advanced.

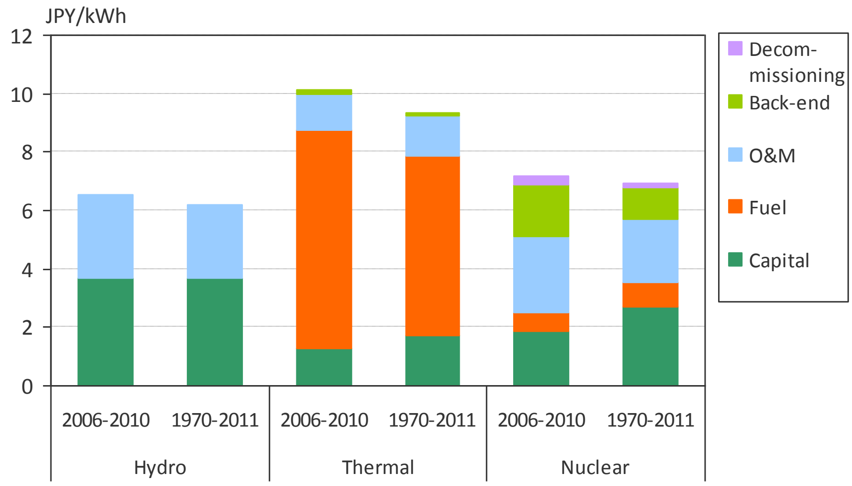


Fig. 3-20 Comparison with previous estimation

(2) Comparison with estimations by Oshima (2010)

Oshima [4] used a similar method to estimate the unit cost for hydro, thermal, and nuclear power generation based on the corporate financial statements of nine power companies from fiscal 1970 to 2007. The previous study [5] provides a detailed account of the differences between Oshima's and the authors' estimations. The main difference is that Oshima's calculations assume a rate base consisting of the fixed assets of the utilities,etc., and multiplying it by the operator's rate of return to estimate the "business reward", and add it to the cost of generating electricity, whereas the authors' calculations distribute and add to the cost the actual interest expenses. Figure 3-21 compares the results of the two studies. Generally the estimated unit costs are higher with Oshima's method. The difference is particularly remarkable for nuclear power generation prior to 1990. This is mainly due to the existence of huge assets, including nuclear fuel assets, relating to the nuclear power plants under construction in this period.

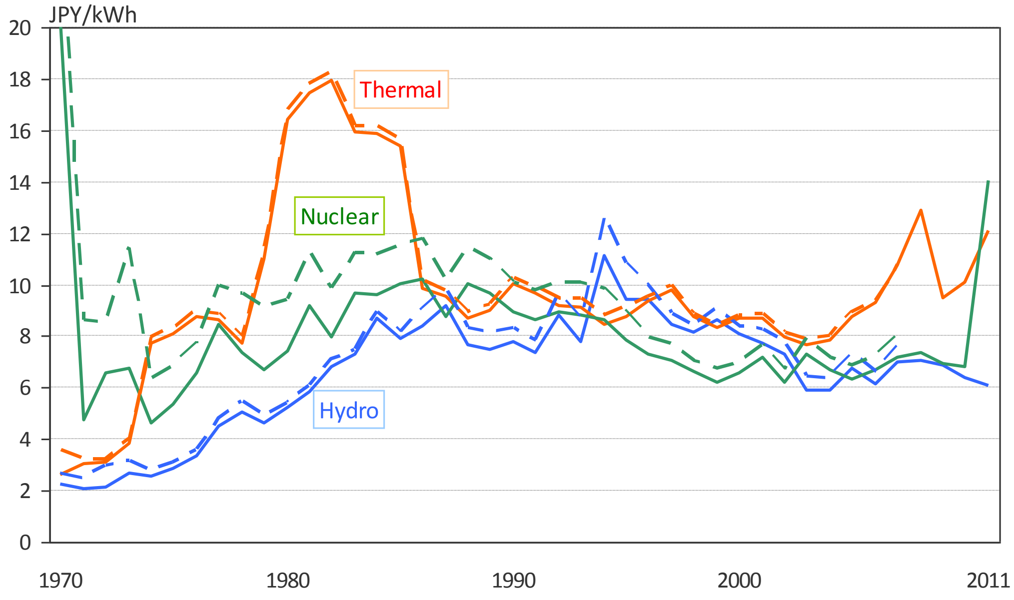


Fig. 3-21 Comparison between Oshima (2010, dotted lines) and authors' estimations (solid lines)

As the name indicate, "power generation costs" or "power generation unit costs" refer to the value obtained by dividing the costs for power generation incurred by the generator of power (i.e. a utility operator) by the amount of power generated. When making the estimations, it is not appropriate to use the "business rewards" or any other expenses, which has no relationship with power generation. In this sense the authrs' method is more appropriate for calculating the unit costs. Nonetheless, Oshima adopted the abovementioned method because the value of fixed assets multiplied by the business rate of return, etc. is used when power companies calculate tariffs and he regards it as a substantial public financial burden. As far as the validity of adding the assumed values of business rewards to the actual power generation costs is concerned, we need to consider the reasons for carrying out these estimations.

Cost estimations using corporation financial statements are performed mainly for two reasons. One is to assess the inherent costs of generating power for each source of electricity, and to put the information to use in future policy. For this purpose, the method provides useful information to supplement cost assessments based on the model plant method (LCOE method). To serve this purpose, however, we must clearly identify and classify the costs involved in generating power and other cost burdens without confusing them, before applying them appropriately in each problem. In addition, as stated in this paper, the cost assessment using corporate financial statements has a strong tendency to reflect a range of external factors and it is necessary to pay utmost attention when using it for future policies. For example, according to our calculations, if we were to use Oshima's method and fix the business rate of return at 3.2%, a value that is close to the current reality, the unit cost for nuclear power generation for 38-year average would decrease from JPY8.64/kWh to JPY7.8/kWh (it should be noted that capital cost for nuclear power generation fluctuates substantially due to the impact of interest rates, not only for Oshima's method, but also for the authors' as indicated in Section 3-2-1). Also, when taking the average, Oshima uses nominal values, which is apparently inappropriate. If, for argument's sake, we use GDP deflators to find the real value, the difference in power generation costs for thermal and nuclear power would expand from JPY1.2/kWh to JPY1.7/kWh.

The second aim involves historical assessments of past energy policy and utility operator's performances. It applies, for example, to the cases of impact assessment of diversification presented in Section 3-2-4. While it is also essential to find the values in real terms for this aim, it is also essential to discuss matters based on actual (not assumed) past data. If we want to conduct a discussion about the costs of power generation, we ought to calculate the cost of power generation correctly and without any confusion. On the other hand, if we want to debate the contribution of each source of electricity to the tariff cost price and its impact on the public financial burden, we should use a breakdown of the cost price used when the utilities actually calculate the tariffs, and not the cost of power generation based on corporate financial statements.

4. Conclusion

This study uses corporate financial reports for nine power companies over a period of 42 years from fiscal 1970 to 2011 to assess the cost of hydro, thermal, and nuclear power generation in terms of actual values over the long term. In comparison with the past study which calculated the cost of nuclear power generation based on corporate financial statements for the recent five years, the longer-term assessment resultss suggest that capital costs are higher by about JPY0.43/kWh due to issues related to amortization. Also, by comparison with the assessment results of the Cost Review Committee, this study confirmed that the O&M costs (the "various expenses", etc.) in the Committee's assessment are assessed higher than the actual average values over the long term. As far as the cost of nuclear power generation in Japan is concerned, there is a great gap between the Committee's estimation and the results of the OECD's assessment, and the former is estimated to be closer to actual past values. Despite some points of contention, it was confirmed that it is on the whole appropriate to discuss future energy policies based on the Committee's estimations.

For hydropower, the authors attempted to assess the cost of power generation including initial investments, by distinguishing between facilities that started operations before and after 1970. However, as it is assumed that pumped-hydro and general hydro differ significantly in terms of the cost of power generation, accurate assessments are an issue for the future.

Assessing costs across a long time series enables us to look in detail at what impact past energy policy has had on actual cost. In particular, the steep rise in the price of fossil fuel prices in the 1980s had a major impact on Japan, and the country has since then devised ways to mitigate risk by making efforts to diversify energy supply sources. The results of this study clearly indicate that it had a great effect on the return of steep price rises after 2005. After the Fukushima Daiichi nuclear power plant accident at the end of fiscal 2010, the power generation mix in Japan again became more concentrated with the decrease in nuclear power generation. In fiscal 2011, the cost of fuel for thermal power as a share of the overall cost of power generation rose to 67%. In fiscal 2012, it is conceivable that the severity of the situation has increased further, but this discussion is slated for a follow-up report. With no prospects in sight for concrete plans for future energy supplies even after the formation of the LDP government, we need to have a clear understanding of energy costs and associated security issues so as to calmly advance the discussions about the nation's future energy options.

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