

Overview of Assessment by Power Generation Cost Verification Working Group

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Summary

This report outlines the assessment by the Power Generation Cost Verification Working Group organized in the Japanese government in 2015. The working group sought to assess nuclear, thermal (fossil fuel-fired) and renewable energy power generation costs in Japan as fairly as possible while considering the latest data made available after the previous estimation by the Cost Estimation and Review Committee in 2011 and revising estimation methods. The 2011 Committee estimated the unit cost for nuclear power generation at 8.9 yen/kWh or more (with the discount rate at 3% and the capacity factor at 70%) covering decommissioning, additional safety measures, reprocessing of spent nuclear fuels, disposal of high-level radioactive wastes, plant location, R&D and accident risks. The working group revised the estimate upward to 10.1 yen/kWh or more reflecting additional damage compensation and safety measure costs after the Fukushima Daiichi Nuclear Power Station accident. The unit power generation cost estimate was also raised for fossil fuels due to exchange rate and other changes and for most renewable energy sources due to additional policy costs, while the estimate for solar photovoltaics was lowered due to an actual decline in solar panel prices. Given that the results change depending on preconditions, it is important to assess the economic efficiency of each power source not only by comparing numerical estimates alone, but also by understanding the changes in the estimates.

Even after discussions at the working group, multiple problems are still left to be solved. For example, how to assess the grid stabilization cost accompanying the massive spread of volatile power sources such as solar photovoltaics and wind power, from which power output changes greatly within a short period of time, the accident risk cost for nuclear and other power sources, and various policy-related costs will have to be studied in the future. Efforts should be continued to refine the assessment taking into account the latest data, as well as other estimation results and the opinions of wide-ranging experts and citizens.

1. Background for Creating Power Generation Cost Verification Working Group

In the autumn of 2011 just after the Fukushima Daiichi Nuclear Power Station accident, the Japanese government created the Cost Estimation and Review Committee to assess power generation costs including power plant location, policy and other external costs in response to citizens' growing interest in nuclear power generation costs¹. The committee tried to comprehensively collect and assess data about nuclear, thermal and renewable energy power generation costs. But additional safety measure costs under the new safety regulation standards implemented in July 2013 and damage from the Fukushima accident were still unclear then, leaving room for further assessment in the future.

After discussions on the "best energy mix" Japan should pursue in the wake of the Fukushima accident continued under a Democratic Party of Japan administration and a Liberal Democratic Party government, the cabinet made a decision in April 2014 on a basic energy plan (Strategic Energy Plan of Japan)², which positions nuclear power as "an important base-load power source contributing to the stability of the energy supply and demand structure" and vows to reduce Japan's dependency on nuclear power "as much as possible by spreading energy conservation measures and renewable energy and improving the efficiency of thermal power generation." Based on the plan, the Strategic Policy Committee of the Advisory Committee for Natural Resources and Energy, an advisory panel to the Minister of Economy, Trade and Industry, created the Long-term Energy Supply and Demand Outlook Subcommittee to deliberate on a specific, quantitative energy mix for 2030 from January 2015. Then, the subcommittee set up the Power Generation Cost Verification Working Group to revise the abovementioned

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¹ Report by Power Generation Cost Verification Working Group (December 19, 2011) [In Japanese]
<http://www.cas.go.jp/jp/seisaku/npu/policy09/archive02.html>

² Strategic Energy Plan of Japan (April 2014) [In Japanese]
<http://www.meti.go.jp/press/2014/04/20140411001/20140411001-1.pdf>

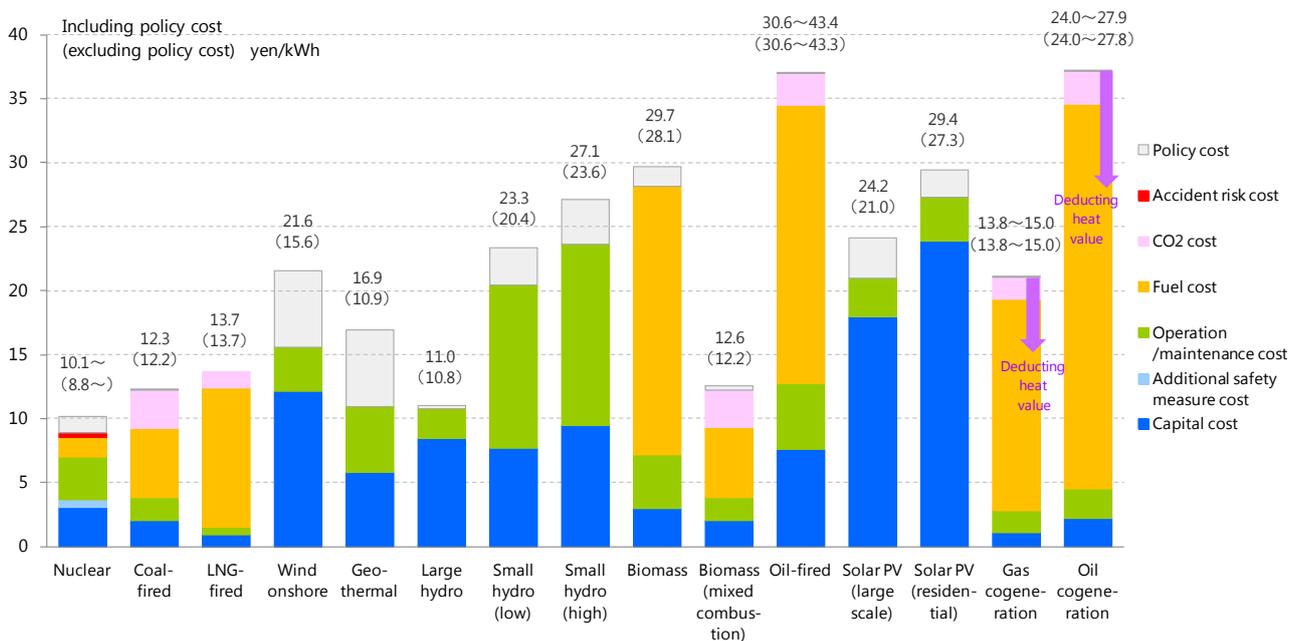
cost assessment based on latest conditions. The working group launched deliberations in February 2015.

Named chairman of the working group was Kenji Yamaji, professor emeritus of the University of Tokyo, director-general of the Research Institute of Innovative Technology for the Earth (RITE), and a member of the Long-term Energy Supply and Demand Outlook Subcommittee. The working group comprises nine members including the author of this report, six of which had served on the Cost Estimation and Review Committee. Following its first meeting on February 18, the working group met every two weeks. At its seventh meeting on May 11, the working group presented its draft report to the Long-term Energy Supply and Demand Outlook Subcommittee³.

This report outlines the assessment by the working group and what would be the future challenges regarding power generation cost assessment. It should be noted that the report represents the author’s personal views rather than those of the working group itself.

2. Example of estimation results

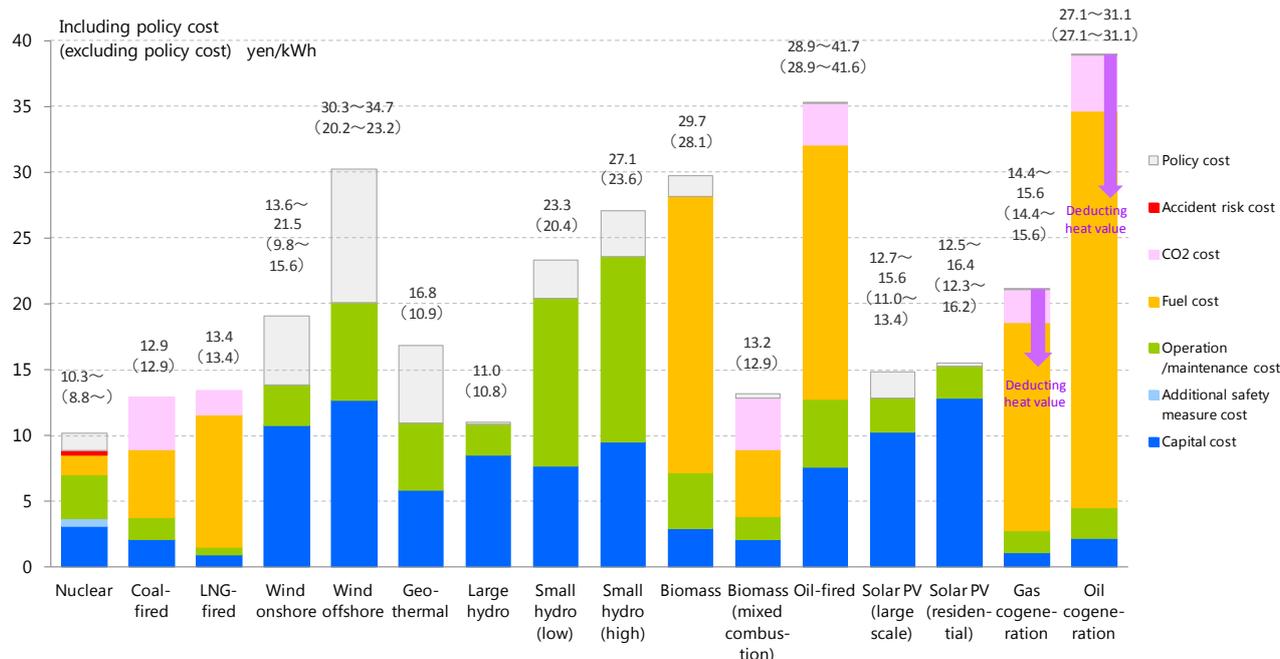
Figures 2-1 and 2-2 indicate some example results of power generation cost estimation by the working group. The “2014 Model Plant” and the “2030 Model Plant” mean the plants that would start operation in 2014 and 2030, respectively, and continue operation for a certain period of time before being shut down and decommissioned. An average unit power generation cost (or levelized cost of electricity, LCOE) is assessed for a lifecycle of each plant in 2014 real prices. The discount rate is put at 3% for all electricity sources, with capacity factors and service lives assumed as indicated in Table 2-1. The estimation results could vary widely depending on preconditions. On the relative superiority of electricity sources, particularly, we should refrain from making any conclusion based on data given in these figures alone. Since the economic efficiency of each electricity source varies depending on how it is used, it is important to understand the changes in the estimates, rather than the results themselves. For more details, see documents published by the Power Generation Cost Verification Working Group.



Source: Power Generation Cost Verification Working Group (2015)

Figure 2-1 Power generation cost estimation results (2014 Model Plant)

³ Power Generation Cost Verification Working Group document (May 2015) [In Japanese]
http://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/#cost_wg



Source: Power Generation Cost Verification Working Group (2015)

Figure 2-2 Power generation cost estimation results (2030 Model Plant)

Table 2-1 Preconditions of above estimation results

	Nuclear	Coal-fired	LNG-fired	Wind onshore	Wind offshore	Geo-thermal	Large hydro	Small hydro	Bio-mass	Biomass (mixed combustion)	Oil-fired	Solar PV (large scale)	Solar PV (residential)	Gas cogeneration	Oil cogeneration
Capacity factor	70%	70%	70%	20%	30%	83%	45%	60%	87%	70%	30%	14%	12%	70%	40%
Service life (years)	40	40	40	20	20	40	40	40	40	40	40	20~30	20~30	30	30

Source: Power Generation Cost Verification Working Group (2015)

In the Cost Estimation and Review Committee’s estimation in 2011 (hereinafter referred to as the previous estimation), the unit nuclear power generation cost was estimated at 8.9 yen/kWh or more with the discount rate put at 3% and the capacity factor at 70%. The unit cost includes the narrowly defined power generation cost (covering the capital cost including plant construction and decommissioning costs, the additional safety measure cost, the operation and maintenance cost, and the nuclear fuel cycle cost including reprocessing and high-level radioactive waste disposal costs), as well as the policy cost including location, subsidies to local governments, research and development costs, and the accident risk cost assumed to cover damage amounting to that inflicted by the Fukushima accident.

Although the estimation by the working group used almost the same method and cost classification as the previous one, the unit nuclear power generation cost rose slightly from the previous estimation, reflecting the damage compensation cost described below and the additional safety measure cost accompanying the implementation of the new safety regulations. Specifically, the nuclear power generation cost stands at 8.8 yen/kWh or more excluding the policy cost, or 10.1 yen/kWh or more including the policy cost, for the 2014 model plant. “Or more” means that the accident risk cost of 0.3 yen/kWh as part of the unit cost of 8.8 yen/kWh (or 10.1 yen/kWh) reflects the Fukushima accident damage (9.1 trillion yen) assumed as the minimum. If the damage increases by 1 trillion yen, the unit accident risk cost (and the overall unit nuclear power generation cost) may rise by 0.04 yen/kWh.

As for thermal (fossil fuel-fired) power generation for the 2014 model plant, the unit cost rose from the previous estimate of 9.5 yen/kWh (for the 2010 model plant with the capacity factor put at 80%) to 11.8 yen/kWh for coal and from 10.7 yen/kWh to 13.5 yen/kWh for LNG. The largest contributor to the rise is a foreign exchange rate change (from 85.7 yen per dollar for the previous estimation to 105.2 yen for the latest estimation). Since Figures 2-1 and 2-2 assume the capacity factor as the same as 70% for nuclear power generation, the unit coal power generation cost in Figure 2-1 nominally rises from 11.8 yen/kWh for the capacity factor of 80% to 12.3 yen/kWh.

While solar PV and wind power generation costs were estimated as ranges for the 2010 model plants in the previous estimation, they were estimated at specific levels for the 2014 model plants in the latest estimation that used data from the Calculation Committee for Procurement Price, etc., which determines tariffs for the feed-in tariff (FIT) scheme. As a new policy cost (covering research and development, and a cost increase for the introduction of the FIT scheme) was added to the costs for the previous estimation, the latest cost estimate for wind power generation posts an increase from the previous one. The estimated cost for solar PV, however, logs a decline due to a solar panel price drop, despite the additional policy cost. The impact of policy cost is great especially on geothermal power generation. Compared with the previous estimate of 9.2-11.6 yen/kWh, the new estimate for the 2014 model plant stands at 10.9 yen/kWh excluding the policy cost or 16.9 yen/kWh including that cost. This is primarily because the internal rate of return (IRR) for geothermal power generation is set at as high as 13% under the FIT scheme.

3. Comparison with the previous estimation and discussion

The estimation by the working group as well as the previous one aimed to comprehensively assess costs for various power generation means with sufficient transparency maintained. As described above, for example, the estimated unit cost for nuclear power generation covers decommissioning, reprocessing and radioactive waste disposal, as well as location, subsidies, research and development, additional safety measures and accident risks. Similarly, estimates for thermal and renewable energy power generation include carbon costs, policy costs and other social costs. MS Excel sheets used for the estimation are made available on the website of the Agency for Natural Resources and Energy, allowing the computation process to be traced completely.

(i) Collecting and reflecting up-to-date data

The estimation method by the working group has not changed largely from the previous one, with the exception of the way of calculating the capital cost as described below. At the same time, the estimation has used new data which were made available after the 2011 estimation. Major changes follow:

a. Additional safety measure cost

In the previous estimation before the implementation of the new safety regulation standards, the amount of 19.4 billion yen per reactor was adopted as the then available estimate of the additional safety measure cost for nuclear power plants. In line with the later establishment of the Nuclear Regulation Authority and the new safety regulation standards, electric utilities implemented safety measures to conform to the new standards, making cost estimates available. If the present regulation standards and examinations continue in the future, additional safety measure cost estimates made available by early 2015 may be deemed appropriate for the estimation. The working group assessed the additional safety measure cost at about 100 billion yen per reactor, after interviewing electric utilities about realized and planned costs for the 11 subcategories of additional safety measures in Table 3-1 for 24 reactors that have been subjected to their applications for examinations about the conformity to the new regulation standards.

Table 3-1 Additional safety measures

Category	Subcategory	Measures
Severe accident measures	(1) Responding to an intentional aircraft crash	1. Creating a specified grave accident response facility 2. Dispersing connection ports, etc.
	(2) Reducing the dispersion of radioactive substances	1. Installing outdoor water dischargers 2. Reducing the dispersion of radioactive substances outside the plant site 3. Diversifying means to cool spent fuel pools
	(3) Preventing containment damage	1. Installing a filtered venting system (BWRs) 2. Preventing hydrogen explosions 3. Diversifying means to cool the containment vessel
	(4) Preventing reactor core damage	1. Deploying alternative potable low-pressure infusion pumps 2. Deploying alternative power supply vehicles 3. Deploying large-capacity pumping vehicles 4. Installing alternative air supply lines for controlling pressurizer relief valves 5. Others 6. Installing accident monitors 7. Installing alternative permanent low-pressure infusion pumps 8. Installing low-pressure infusion plumbing 9. Installing alternative permanent power sources 10. Installing self-cooling systems using filling-type high-pressure infusion pumps
	(5) Others	1. Installing portable monitoring posts 2. Enhancing safety system batteries (changing capacity for existing batteries) 3. Installing power supply cables for sharing among reactors 4. Constructing quakeproof office buildings 5. Others 6. Installing emergency measure-related equipment
Design standards	(6) Measures to internal overflow	1. Detecting leaks from plumbing 2. Installing overflow expansion prevention systems (including dams) 3. Installing watertight doors
	(7) Measures to natural phenomena - volcanic eruptions, tornadoes and forest fires	1. Setting up firebelts (to counter forest fires) 2. Measures to counter tornado-carried objects and prevent objects from flying apart 3. Measures to counter volcanic eruptions
	(8) Measures to fires	1. Installing different types of fire sensors 2. Installing firefighting equipment 3. Enhancing fire resistance to separate grids 4. Others
	(9) Power source reliability	1. Increasing fuel tanks for emergency diesel generators
	(10) Resistance to earthquakes	1. Improving the seismic safety margin 2. Stabilizing peripheral slopes
	(11) Resistance to tsunami	1. Building seawalls (anti-tsunami measure)

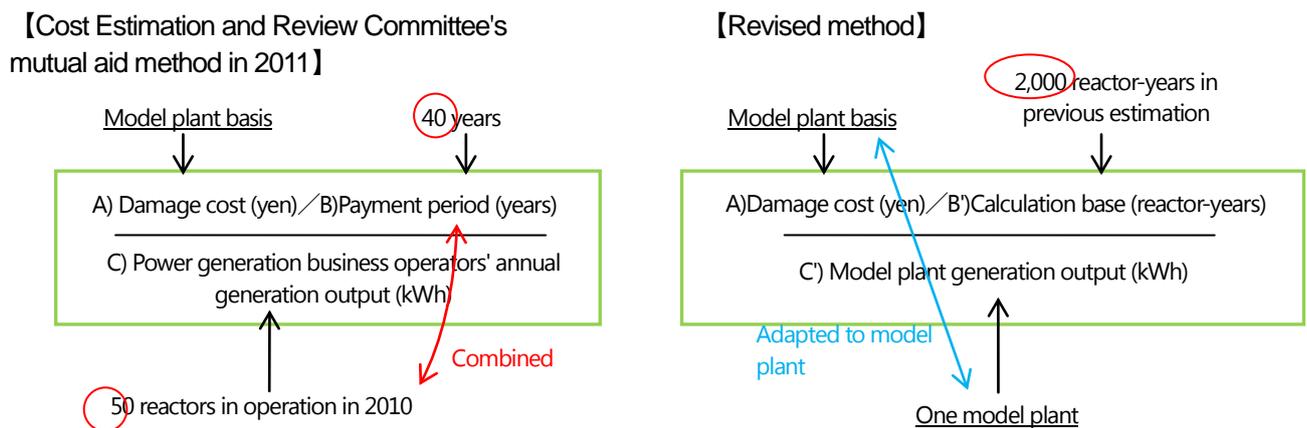
Source: Power Generation Cost Verification Working Group (2015)

The amount of 100 billion yen is an additional safety measure cost for an existing reactor. If a new reactor is to be constructed, a plumbing modification, for example, may be put into the design stage and cost far less than for an existing reactor. The working group interviewed relevant utilities about 38 additional safety measures (as given in Table 3-1) and specified a discounting ratio for the cost of each measure for a new reactor. Eventually, the group assessed the total additional safety measure cost for a new reactor at some 60% (60.1 billion yen) of the 100 billion yen amount for an existing reactor. This additional safety measure cost has a considerable impact on the unit nuclear power generation cost. Given the capacity factor of 70% and the discount rate of 3%, the measure is estimated to account for 0.6 yen/kWh of the unit cost.

b. Accident risk cost

In the previous estimation, the Fukushima accident damage was estimated at 5.8 trillion yen covering costs that were identified then. It was raised to 9.1 trillion by the working group reflecting the latest data. The amount covers the Fukushima Daiichi Nuclear Power Station's decommissioning, compensation, radiation decontamination, interim storage of radioactive wastes and various administrative costs.

In the previous estimation, the accident risk cost was assessed as a cost over 40 years "based on the concept of mutual aid between power generation utilities." It was assessed at 0.5 yen/kWh by dividing the damage amount of 5.8 trillion yen by annual nuclear power generation output (272.2 billion kWh on a FY2010 result basis) by 40 (years). Since the damage amount of 5.8 trillion yen represented the then identified amount and was expected to increase in the future, the accident risk cost was estimated to rise by 0.09 yen/kWh as the damage amount increases by 1 trillion yen. This means that the committee calculated the accident risk unit cost as equivalent to that for the Fukushima accident under an assumption that an accident would occur every 40 years.



Source: Power Generation Cost Verification Working Group (2015)

Figure 3-1 The way of calculating unit accident risk cost

The working group decided to follow a similar method. But the adequacy of using the FY2010 actual power generation output (272.2 billion kWh) as the denominator was questioned anew. Eventually, the working group replaced⁴ the denominator of "272.2 billion kWh x 40 years" in the previous estimation with "50 reactors x annual generation output per reactor x 40 years" or "2,000 reactor-years x annual generation output per reactor," adopted "2,000 reactor-years" as a "calculation base" for computing the unit cost and reduced the problem to how to set the base⁵. Although the working group

⁴ Since the generation output of 272.2 billion kWh correctly differs from the total annual generation output of the 50 model plants (the latter is larger due to reactor capacity differences), the replacement can slightly change the unit accident risk cost. But the impact of such change is not as great as the problem of how to set the calculation base.

⁵ It should be noted that the replacement does not only represent simple change in the calculation method. Under the previous method, a total damage cost for Japan was initially given so that the accident risk cost would remain unchanged irrespective of nuclear reactors in operation. Under the new method, however, the total accident risk cost doubles as the number of reactors in operation doubles. The latest method thus produces a more reasonable result.

was never divided over this replacement, the members differed over how to set the calculation base.

First, the calculation base is deemed different from the reciprocal of the accident frequency rate. An opinion is that even if the assumed accident frequency rate is one accident per 10,000 reactor-years, for example, the adoption of 10,000 reactor-years for the estimation of the accident risk response cost may lead to underestimation in terms of risk premium⁶. The calculation base is designed only for computing the accident risk cost as part of the unit nuclear power generation cost and is not necessarily linked directly to a nuclear damage compensation system or an insurance premium rate. Then, how to set the calculation base becomes an important matter for consideration.

A working group member indicated an opinion that since the Nuclear Regulation Authority assumes the accident frequency rate of one accident or less per one million reactor-years as a safety target, it is adequate to use this figure for computing the accident risk. Another opinion said as there is no specific reason for adopting any other figure than 2,000 reactor-years used in the previous estimation, the figure should be adopted.

Finally, the working group referred to international accident frequency rates⁷ and the probabilistic risk assessment (PRA) for each nuclear power station after the Fukushima accident, which relatively indicated that if only one of all available safety measures is taken, the accident frequency rate would be roughly halved from the level before the implementation of the measure. If the calculation base's relative relationship with the accident frequency rate remains unchanged, the number of reactor-years may double after the accident frequency rate is halved through the implementation of one safety measure. In the estimation by the working group, therefore, the calculation base was doubled from 2,000 reactor-years in the previous estimation to 4,000 reactor-years, leading to the unit accident risk cost of 0.3 yen/kWh corresponding to the damage amount of 9.1 trillion yen. As the damage amount increases by 1 trillion yen, the cost may rise by 0.04 yen/kWh.

An enormous amount of money has actually been spent on safety measures and is taken into account in the estimation of the unit nuclear power generation cost as noted above. As far as safety measures are designed to reduce the accident frequency rate, it is reasonable to project a calculation base change meeting any implemented safety measures. But no consensus exists on how the accident frequency rate is specifically related to the calculation base or how the accident frequency rate can be projected to decline specifically through the implementation of safety measures. Although the working group has made one conclusion, the questions are apparently required to be considered further in the future.

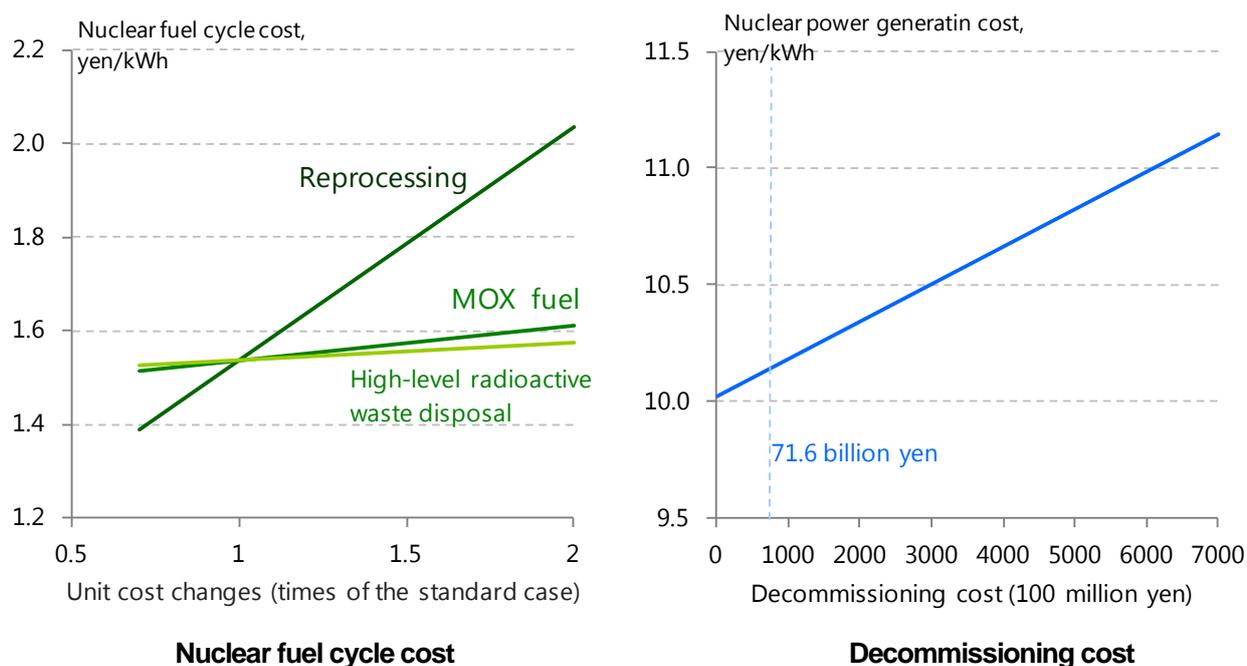
c. Nuclear fuel cycle cost

As for the nuclear fuel cycle cost, the working group used the same assumption ("current situation model") as in the previous estimation, assuming that a half of spent nuclear fuels will be directly reprocessed and recycled, with the remainder subjected to interim storage before reprocessing. But, the cost value slightly changed, reflecting safety measure costs for responding to the new regulation standards and a change in foreign exchange rates. Specifically, the front end cost (i.e. a cost for acquisition of nuclear fuels) rose slightly from 0.84 yen/kWh to 0.95 yen/kWh and the back end cost (a cost for reprocessing, interim storage and disposal of high-level radioactive waste, etc.) from 0.55 yen/kWh to 0.59 yen/kWh under the discount rate of 3%. But the total of front and back end cost changes was limited to 0.14 yen/kWh, exerting no major impact on the total unit nuclear power generation cost.

The nuclear fuel cycle and decommissioning costs have been subjected to a sensitivity analysis for cases where costs will increase more than expected. As indicated in Figure 3-2, a reprocessing cost change can exert a relatively great impact. If the reprocessing cost increases 1.5-fold due to a delay in a reprocessing plant construction program or a rise in construction cost, the unit nuclear fuel cycle cost (and the overall unit nuclear power generation cost) may increase by 0.25 yen/kWh. Given that the high-level radioactive waste disposal unit cost is as small as 0.04 yen/kWh, however, even this cost's rise of several times may have little impact. If the reactor decommissioning cost doubles from the present estimate of 71.6 billion yen per reactor, the unit nuclear power generation cost may rise by 0.1 yen/kWh.

⁶ As for various issues related to the accident risk cost, see "Analysis on Methods for Assessing Accident Risk Cost for Nuclear Power Generation", Y. Matsuo. (to be put on the website of the Institute of Energy Economics, Japan).

⁷ Past nuclear power plant operations in the world total about 15,000 reactor-years. If the number of major accidents is put at three (Three Mile Island, Chernobyl and Fukushima), the accident frequency rate would be about one accident per 5,000 reactor-years.



Source: Power Generation Cost Verification Working Group (2015)

Figure 3-2 Sensitivity analysis for nuclear fuel cycle and decommissioning costs

A sensitivity analysis of the nuclear fuel cycle cost was conducted in the previous estimation as well. A relevant document includes details about the background⁸. According to the document, the reprocessing cost may increase some 1.3-fold if the reprocessing plant construction cost expands by 3 trillion yen from the present estimate with the construction plan delayed for five years. If the reprocessing cost rises 1.5-fold, the unit nuclear power generation cost is estimated to increase by 0.25 yen/kWh. This result is almost similar to the sensitivity analysis result for the estimation as indicated in Figure 3-2.

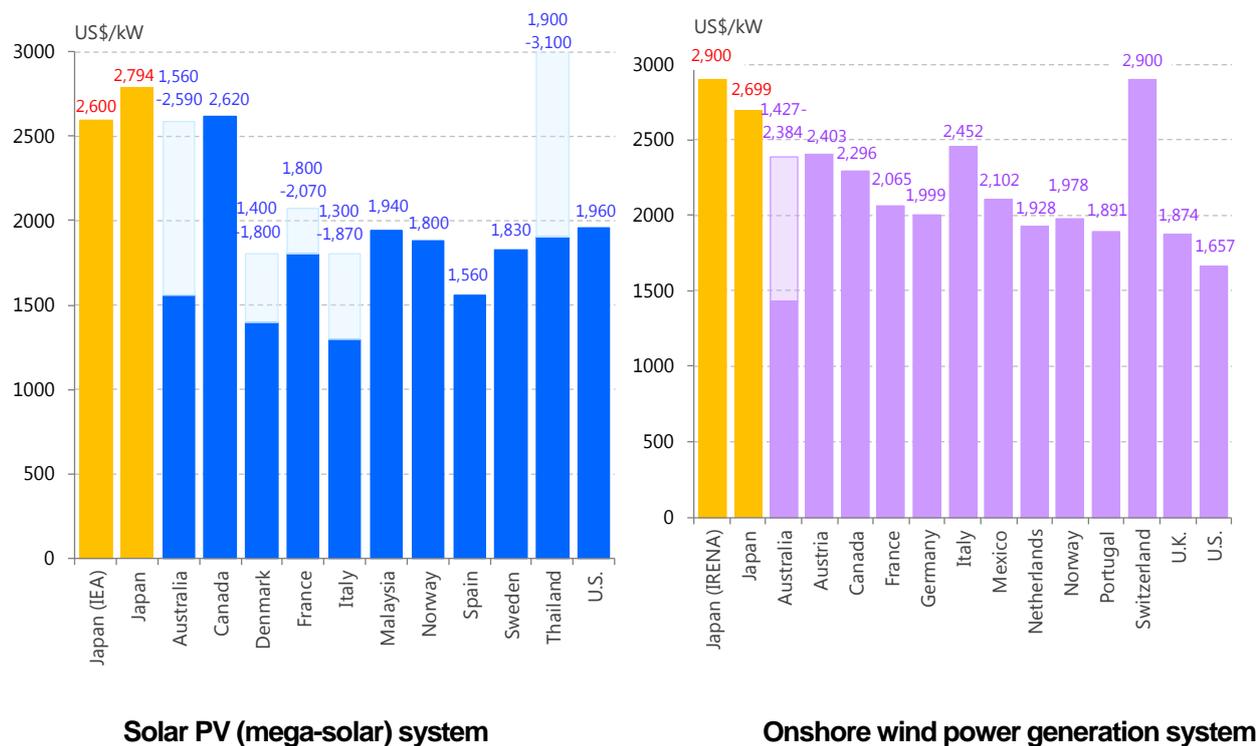
d. Cost for renewables

As for renewable energy, major specifications such as unit construction costs have been provided for the introduction of the FIT scheme and made available for cost estimation. As for solar PV, particularly, the decline in the solar panel cost has been remarkable. Reflecting the panel cost drop, the unit solar PV generation cost has declined considerably from the previous estimation. While the unit construction cost for residential solar PV systems was given as a range of 480,000 to 550,000 yen/kW in 2010 for the previous estimation, the cost is put at a far lower specific level of 364,000 yen/kW in 2014 for the new estimation, based on the assessment by the Calculation Committee for Procurement Price, etc., which determines tariffs for the FIT scheme. Similarly, the cost for “mega-solar” power generation (i.e. large-scale ground-mounted solar PV power generation) has been assessed at a specific level of 294,000 yen /kW in 2014 against a range of 350,000 to 550,000 yen/kW in 2010 for the previous estimation. The onshore wind power generation cost has also been assessed at a specific level of 284,000 yen/kW against a range of 200,000 to 350,000 yen/kW in 2010 for the previous estimation.

Unit construction costs for solar PV and wind power generation systems in Japan are higher than in other countries. For example, the unit construction cost for “mega-solar” systems in Japan is assessed at \$2,794/kW in the latest estimation (for 2014 with the exchange rate at 105 yen per dollar) or \$2,600/kW as estimated by the International Energy Agency (IEA), against less than \$2,000/kW in other countries. The unit construction cost for onshore wind power plants in Japan is assessed at \$2,699/kW in the latest estimation or \$2,900/kW as estimated by the International Renewable Energy Agency (IRENA) against around \$2,000/kW in many other countries. Apparent factors behind the cost gap include higher personnel costs,

⁸ Japan Atomic Energy Commission, “Estimating Nuclear Fuel Cycle Cost”
http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf

complex topography and FIT scheme introduction backgrounds in Japan⁹. We may have to fully recognize the current situation as it is.



Solar PV (mega-solar) system

Onshore wind power generation system

Sources: IEA PVPS (2014), "Trends 2014 in photovoltaic applications,"

IRENA (2015), "Renewable power generation costs in 2014."

Figure 3-3 International comparison of unit construction costs for solar PV and wind power generation systems

The time series trends in Figure 3-4 indicate that the solar PV system price has declined rapidly in Japan as well. But the construction cost for wind power plants continued rising until 2008 and has leveled off since then, according to IEA. The unit construction cost for wind power plants rose globally between 2004 and 2008¹⁰ due apparently to materials price hikes and supply shortages accompanying the global spread of wind power generation systems. But the cost increase in Japan was far more remarkable than in other countries, indicating some special factors such as complex topography.

Under such conditions, we may have to consider how far unit construction costs for solar PV and wind power generation systems would decline toward 2030. In the previous estimation, the committee projected that solar PV system prices would decline according to a learning curve accompanying the global solar PV generation capacity increase based on projections by the European Photovoltaic Industry Association (EPIA) and Greenpeace¹¹. In contrast, the working group adopted an IEA outlook¹² that is more conservative than the EPIA and Greenpeace projection. As for wind power generation, the working group considered a scenario in which system prices would decline in line with the relevant IEA roadmap¹³, as well as another scenario in which the construction cost would remain unchanged from 2014, reflecting the past trends.

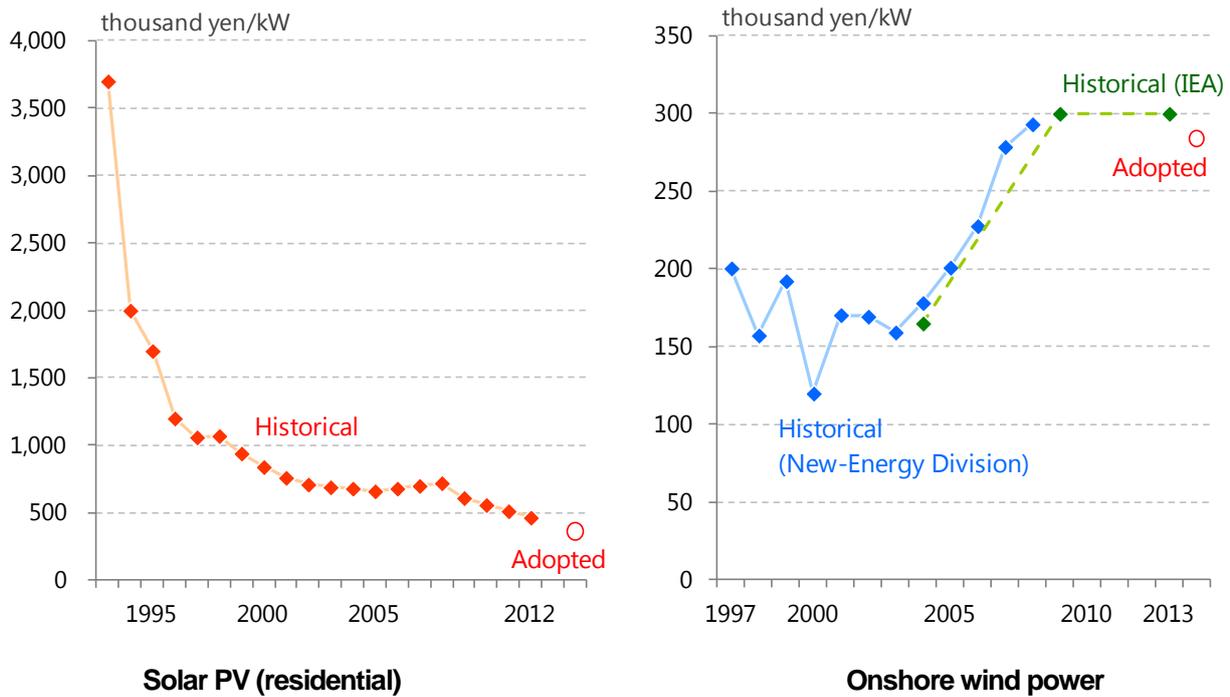
⁹ Several studies point out that high FIT tariffs in Japan have worked to decelerate the decline in solar panel prices. They include an opinion presented by Prof. Nomura at the fourth meeting (on March 10, 2015) of the Long-term Energy Supply and Demand Outlook Subcommittee. http://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/004/pdf/004_11.pdf [in Japanese]

¹⁰ International Renewable Energy Agency (IRENA), "Renewable energy technologies: cost analysis series: Wind power," (2012).

¹¹ European Photovoltaic Industry Association (EPIA) and Greenpeace, "Solar Generation 6," (2011).

¹² International Energy Agency (IEA), "World Energy Outlook 2014," (2014).

¹³ IEA, "Technology roadmap – Wind energy 2013 edition," (2013).



Sources: Residential solar PV (system price): NEDO (2013), “Renewable Energy Technology White Paper”

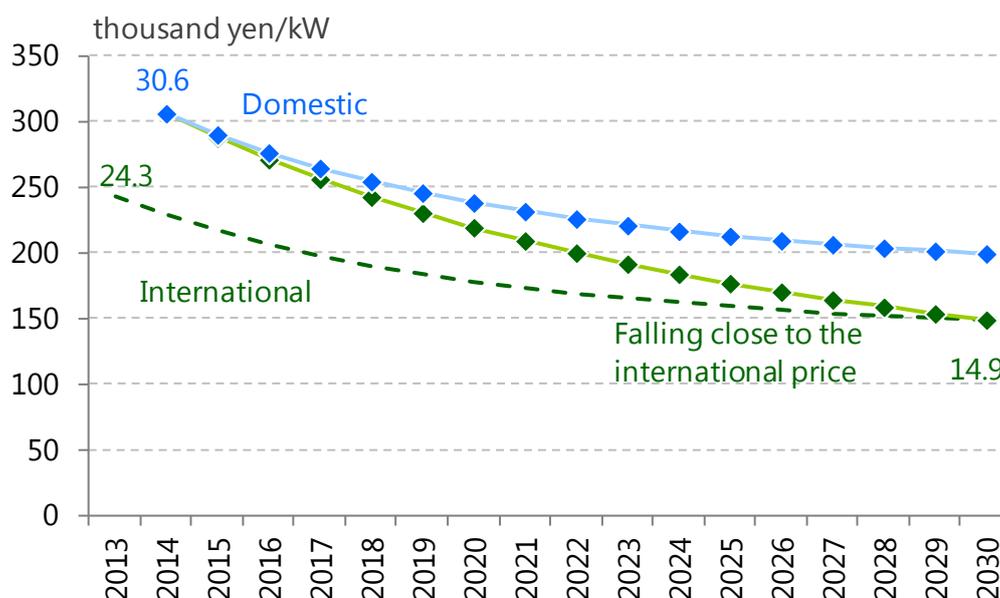
Onshore wind power (plant construction cost): 29th meeting of the New-Energy Division (2008), IEA Wind Annual Report (2004-2013)

Figure 3-4 Time-series trends of unit construction costs for solar PV and wind power generation systems

The estimation by the working group made a difference from the previous one by giving consideration to the present situation where unit construction costs in Japan are higher than in other countries. In addition to the abovementioned scenarios, the working group considered a scenario in which the unit construction costs would decrease further to international levels in the future.

The unit cost for residential solar PV systems is assessed at 206,000 to 274,000 yen/kW based on the abovementioned scenarios against 189,000 to 384,000 yen/kW in the previous estimation. Although the two estimates are roughly the same, the estimated range for the new estimation is narrower. The unit cost for mega-solar systems is assessed at 185,000 to 233,000 yen/kW against 158,000 to 400,000 yen/kW in the previous estimation. That for onshore wind power plants is given at 205,000 to 284,000 yen/kW against 177,000 to 350,000 yen/kW. Both ranges in the new estimation are narrower.

When we consider the projected penetration of solar PV panels or any other products, we can suspect that relevant industry groups’ projections tend to have an upward bias. From this viewpoint, the working group has worked out an outlook for falling solar PV system prices with their approach to international levels taken into account, instead of adopting an outlook given by any solar PV system industry group, as noted above. Therefore, the new estimation can be seen as more accountable. Given that the estimated ranges obtained in the previous estimation were very wide and effectively failed to predict future costs, the working group’s attempt to narrow the estimated ranges in the latest estimation may be viewed as an improvement, although we can never accurately anticipate any future trends. Renewable energy power generation costs are globally falling in line with the advancement and diffusion of relevant technologies. We will have to keep watching relevant trends in Japan as well.



Source: Power Generation Cost Verification Working Group (2015)

Figure 3-5 Projected declines in residential solar PV module inverter and other relevant costs

As the service life for solar PV systems, the previous estimation assumed 35 years in and after 2020 (for both residential and mega-solar systems) based on EPIA data. In contrast, the working group assumed the service life to be extended from 20 years at present to 30 years in 2030, based on technology development targets of the New Energy and Industrial Technology Development Organization (NEDO) and other data. As is the case with the solar PV system penetration outlook, the working committee's attempt to refrain from adopting an outlook of any relevant industry group may have to be viewed as an improvement.

e. Sample plants for thermal and hydro power generation

As for thermal and hydro power generation, the working group selected several plants that have been recently built as sample plants, for which data have been used for estimation. As a result, the unit construction cost for coal power plants has risen from 230,000 yen/kW for the previous estimation to 250,000 yen/kW. The thermal efficiency of LNG-fired power generation has also increased slightly from 51% to 52%. A more remarkable change has come for general hydro power plants, for which the unit construction cost has declined from 850,000 yen/kW to 640,000 yen/kW.

As for oil-fired power generation, newest plants had been adopted as sample plants in the same way as for coal- and LNG-fired power generation. But even the newest oil-fired power plants were constructed in the 1980s or 1990s, failing to reflect latest technologies. Therefore, the working group, though using traditional sample plants for 2014 period, has assumed the realization of a supercritical oil-fired power plant (with the thermal efficiency at 48%) for 2030.

(ii) Policy cost

In the latest estimation, the working group has also reviewed the concept of power generation cost. Particularly, the group has questioned why the previous estimation took into account no policy cost for renewable energy while it counted location, research and development costs for nuclear power generation. The working group also assessed the "unit cost" for FIT scheme implementation that started after the previous estimation, considering the extra charge as a social cost. The tariff under the FIT scheme, however, is set as a combination of a power generation cost and an adequate profit. In this sense, it may be unreasonable to describe the FIT tariff including the adequate profit as "a power generation cost." So, the working group has decided to provide both the power generation cost excluding the policy cost and the widely defined "power generation cost" including the policy cost.

The policy cost is divided into the FIT-caused cost increase (that conceptually and roughly corresponds to the gap between the actual tariff and the narrowly defined power generation cost) and the other policy costs. Counted as part of the other policy costs are location, disaster prevention, public relations, human resources development, assessment and research, and technology development costs as well as contributions to international organizations according to the FY2014 central government budget. Excluded from these costs for the estimation are those which are related to energy in general rather than specific power sources, which would contribute to power generation outside Japan and which are needed for research and development of future technologies deemed to be linked little to present power generation system. A controversial issue in this respect was whether to include costs for developing advanced technologies such as fast breeder reactors (FBRs), nuclear fusion and innovative solar cells. Eventually, the working group has included the FBR development cost while excluding nuclear fusion and innovative solar cell development costs. If the unit power generation cost including the policy cost given in this estimation is used for assessing the economic efficiency of the energy mix for 2030, therefore, the power generation cost will explicitly include a FBR research and development budget. But I understand that the working group's discussions do not represent its commitment to continue FBR research and development in Japan in the future. So, we will have to further consider how to handle the unit research and development cost.

By dividing FY2014 government expenditures as aggregated in this way by the power generation output, we can calculate the policy cost's contribution to the unit power generation cost. The power generation output as the denominator, as well as the expenditures as the numerator, was to be based on actual results in FY2014. Since all nuclear reactors in Japan remained offline in FY2014, however, the working group has used the total output from 43 reactors excluding those subjected to decommissioning, assuming a load factor of 70%. Given that most renewable energy sources are being introduced with their present power generation output being far smaller than the assumed future capacity, the working group has assumed the total capacity certified under the FIT scheme for assuming power generation output. Specifically, each figure given in Table 3-2 is used as a denominator for computing the unit power generation cost.

Table 3-2 Annual power generation output used for calculating policy cost

	Nuclear	Coal-fired	LNG-fired	Oil-fired	Large hydro	Cogeneration	Small hydro	Geo-thermal	Solar PV	Wind onshore	Wind offshore	Bio-mass	Fuel cell
Annual output, TWh	257.8	284.5	405.7	139.8	38.8	51.4	52.5	10.4	93.3	13.5	—	28.9	4.3
Note	Estimate	Historical	Historical	Historical (include LPG, etc.)	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	—	Estimate	Estimate

Source: Power Generation Cost Verification Working Group (2015)

Working group members presented different opinions on what part of the R&D cost should be included into the policy cost and how the R&D cost components included in the policy cost should be positioned, as was the case with the accident risk cost. It should also be noted that no additional cost corresponding to the unit policy cost estimated here will actually emerge when a certain power source is used for generating power.

Estimation of the unit power generation cost is nothing other than a rough assessment of the marginal cost of power generation. In this sense, only the costs that change depending on power generation output should be subject to assessment. The R&D cost, for example, depends on specific objectives for future technology development and cannot be explicitly linked to power generation output. For this reason, the policy cost should be recognized as characteristically different from the more narrowly defined power generation cost. Therefore, it has been appropriate for the policy cost to have been indicated separately for every power source in the latest estimation.

(iii) Capital cost

The capital cost computation method has been revised for the latest estimation. Although the capital cost accompanying power plant construction had been counted as a depreciation cost in the past estimations (by the Cost Estimation and Review Committee in 2011 and by the Subcommittee to Study Costs and Other Issues in 2004), it has been treated as an initial investment cost instead of a depreciation cost in the latest estimation, as is the case with the estimation by the Organization for Economic Cooperation and Development (OECD)¹⁴, etc. This revision has led the capital cost to rise for every power source. Particularly, unit power generation costs for nuclear and renewable energy rise more than for thermal power generation featuring lower capital ratios.

(iv) Grid stabilization cost

In the previous estimation, the committee attempted to assess the cost for stabilizing grids when volatile power sources such as solar PV and wind are introduced. The working group revised the grid stabilization cost estimation method to assess the cost more in detail. The diffusion of volatile power sources is expected to affect the overall power generation efficiency by lowering the capacity factor for thermal power plants, increasing the start and stop frequency, creating the need for backup power sources and increasing power losses due to the expanded use of pumped storage. The grid stabilization cost for volatile power sources (solar PV and wind) has been estimated at 300 billion yen per year for the volatile power generation output of 66 billion kWh (accounting for 6% of Japan's total power generation), at 470 billion yen for the output of 93 billion kWh (accounting for 9%) and 700 billion yen for the output of 124 billion kWh (accounting for 12%). If the annual cost is simply divided by power generation output from volatile power sources, the unit grid stabilization cost may turn out to be 4.5 to 5.6 yen/kWh. Here, any cost for enforcing connections between regional grids has not been taken into account. The estimation also has failed to consider gaps between regions in potential solar PV and wind power generation capacities, resulting in underestimated costs, as agreed at the working group.

The grid stabilization cost would be computed only after a specific energy mix is determined. It is not attributable to any single power source. Therefore, attention should be paid to the point that the cost fails to be taken into account for the unit power generation cost by source given in Figures 2-1 and 2-2 and should be interpreted as an additional cost.

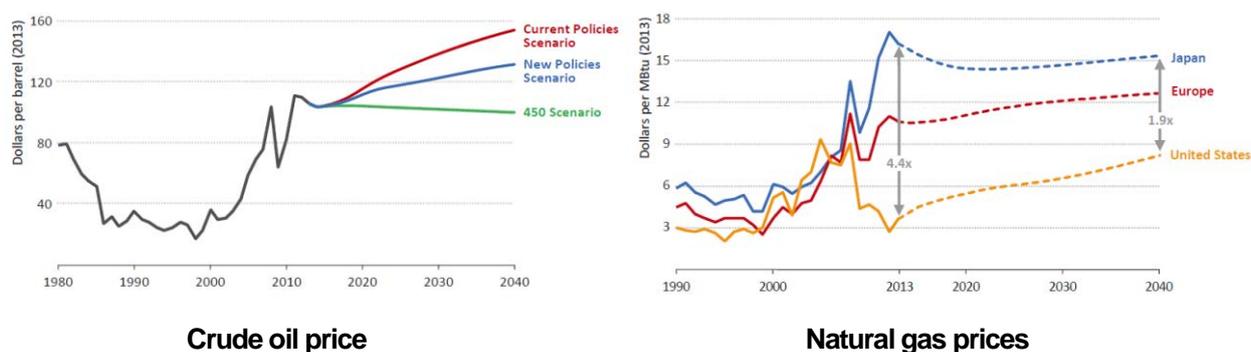
(v) Energy and CO₂ prices

At a meeting of the Long-term Energy Supply and Demand Outlook Subcommittee before the working group's first meeting, one member expressed an opinion that multiple scenarios should be assumed for primary energy prices in response to the crude oil price plunge since the second half of 2014¹⁵. Later discussions at the working group decided that it should assume primary energy prices based on the New Policies Scenario (NPS) in the IEA's World Energy Outlook 2014 (WEO 2014) for the standard case, while conducting a sensitivity analysis of primary energy prices. Specifically, the CIF crude oil import price for Japan has been assumed to rise moderately from \$110.5 per barrel in 2013 to \$127.5/bbl in 2030. The CIF LNG import price has been projected to fall slightly from \$844.7 per ton in 2013 to \$761.2/t. A factor behind such assumption is that energy experts generally expect that crude oil prices, though falling currently, would rise back to earlier projected levels¹⁶. While no one can predict future crude oil prices, the expectation seems to be reasonable at present. According to the sensitivity analysis, a 10% change in assumed primary energy prices is estimated to change the unit coal-fired power generation cost by 0.4 yen/kWh, the unit LNG-fired power generation cost by 0.9 yen/kWh and the unit oil-fired power generation cost by 1.5 yen/kWh. Given uncertainties about the price assumption, future fluctuations in energy prices could exert a considerable impact on power generation costs.

¹⁴ OECD/NEA, IEA, Expert Group on Projected Costs of Generating Electricity
<https://www.oecd-nea.org/ndd/egc/2014/>

¹⁵ The CIF crude oil import price for Japan rapidly declined from 71,414 yen per kiloliter (\$111.6/bbl) in July 2014 to 41,225 yen/kL (\$54.7/bbl) in March 2015. (Source: IEEJ, "EDMC Energy Trend 2015")

¹⁶ For example, the Annual Energy Outlook 2015, released by the U.S. Department of Energy in April 2015, projects that the crude oil price (the West Texas Intermediate price in 2013 constant dollars) would rise from \$52.7/bbl in 2015 to \$99.5/bbl in 2030 and to \$135.7/bbl. The IEA's Energy Technology Perspectives 2015, released in May 2015, assumes the international crude oil price at \$123/bbl in 2030 and \$137/bbl in 2050 under the central 4 degrees scenario.



Note: The Power Generation Cost Verification Working Group has used IEA assumptions in the New Policies Scenario that were adjusted according to Japan's actual CIF import prices for crude oil and coal. As for natural gas (LNG) prices, it has used the IEA assumption for Japan.

Source: IEA, "World Energy Outlook 2014"

Figure 3-6 Crude oil and natural gas price assumptions in the IEA WEO 2014

Similarly, the working group has assumed the CO₂ price in line with the NPS of the IEA WEO 2014. Given that no explicit assumption for Japan exists in the scenario, however, the working group has adopted \$22/tCO₂ in 2020 and \$30/tCO₂ in 2030 (in 2013 constant dollars) for EU.

The NPS represents a scenario in which the future temperature rise would fail to be limited to 2°C. Therefore, attention should be paid to the point that an additional adaptation cost or environmental damage could arise under the scenario. Under the "450 Scenario" where adaptation measures would be adopted for addressing the climate change problem, a much higher CO₂ price of \$100/tCO₂ in 2030 would be required, according to the IEA. The working group, however, has assumed a more moderate NPS level as the CO₂ price, taking into account the fact that there is also an opinion that adaptation could help lower the required cost to a much smaller level. We may have to fully recognize that greenhouse gas emissions' damage to human beings could be greater than expected. According to a sensitivity analysis by the working group, a 10% change from the abovementioned CO₂ price assumption would change the unit coal-fired power generation cost by 0.1 yen/kWh, the unit LNG-fired power generation cost by 0.1 yen/kWh and the unit oil-fired power generation cost by 0.1 to 0.2 yen/kWh.

4. Future challenges

As explained above, the Power Generation Cost Verification Working Group has reviewed and revised the methodology and other aspects and attempted to make a wider, more accurate assessment than the previous estimation by having it reflect up-to-date data. The attempt might have been roughly successful. But many problems are still left for future study. It is indispensable for us to continue improvement efforts.

First, how to handle the policy cost may be a problem that should be studied further. In the estimation by the working group, the additional cost related to the FIT scheme, the nuclear and other power plant location cost and the R&D cost have been included into the policy cost. Of these costs, the working group determined those other than the additional FIT cost by dividing relevant annual government budget figures by power generation output. Particularly, the group's adoption of the certified capacity under the FIT scheme for the calculation of power generation output may be taken as arbitrary. If the standard of the cost that changes in proportion to power generation output is adopted, the additional FIT cost and the plant location cost may meet the standard. But the R&D cost may not in general. In this way, there are some different kinds of costs included into the policy cost. What to include into the policy cost, how to compute it and how to position the computation results would have to be studied further.

The biggest problem for further study regarding the methodology would be the accident risk cost, which has been computed by setting the damage amount as equivalent to the Fukushima accident damage and the reactor-years as the calculation base. Both figures are uncertain and may have to be studied further. There is no guarantee that a possible future accident would bring about the same damage as the Fukushima accident. The amount of accident damage may not be constant

but change according to some probability distribution. As efforts to assess accident risks have continued worldwide, we may have to study the accident risk cost while referring to such latest studies.

As described above, the working group has attempted to meticulously assess the grid stabilization cost and the attempt has been successful to some extent. But the methodology should not be rated as completely satisfactory. The method may have to be improved further, taking into account the expected massive diffusion of renewable energy.

We may have to give full consideration to these problems and review and revise estimates in pursuit of more accurate assessment based on up-to-date data. Particularly important would be the renewable energy cost trend. As explained in this report, solar PV and wind power generation in Japan is more costly than in other countries. Meanwhile, renewable energy costs have continued falling in foreign countries. It is strongly hoped for that such costs are reduced further in Japan to cut the heavy burden of the FIT scheme on the people. No one can predict exactly how far the costs could be lowered in the future.

Also important will be how to explain the estimation method and results to the people in an easy-to-understand manner and how to proceed with discussions with a wide range of people, including those who have different views. In parallel to the discussions, the working group received information from a wide range of people under a campaign for providing information for the verification of power generation costs over a month between early March and early April. The group considered the provided information and opinions, reflected some of them in the estimation and decided that the others had already been reflected or viewed as inappropriate for the reflection. It has attempted to collect information and refer to as wide a range of opinions as possible at present in order to make an unbiased assessment. But the actual situation always changes. Tomorrow's wind could differ from today's. Therefore, we may have to continue study and dialogue in the future.