Analysis of Solar Power Generation Costs in Japan 2021

October 2021

Acknowledgements

In compiling this report, several power plant operators provided us with cost data of their plants, as well as advice regarding analysis. Although we are not able to list the names of each individual, we would like to express our sincere gratitude to everyone who cooperated in this study.

Author

Keiji Kimura, Senior Researcher, Renewable Energy Institute

About Renewable Energy Institute

Renewable Energy Institute is a non-profit think tank which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Son Masayoshi, Chairman & CEO of SoftBank Corp., with his own resources.

Part of this publication was supported by the German Federal Ministry of Economic Affairs and Energy.

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Introduction: Study Background and Objectives

This report is the follow-up to a report we published in 2019, “Solar Power Generation Costs in Japan: Current Status and Future Outlook” (the “2019 report”), and it analyzes the most recent trends in solar PV costs in Japan. In the same way with the 2019 report, the analysis is based on cost information obtained from solar PV power plant operators on investment costs and operation and maintenance costs and looks again at the current cost structure of solar PV in order to analyze the current status of solar PV generation costs in Japan.

Methods of the study

We administered a questionnaire in July 2021 to a random sampling of approximately 1,000 solar PV plant operators in order to clarify the current cost structure of solar PV and its determinant factors. The study targeted commercial providers, so solar PV facilities owned by individuals (regardless of size) were automatically excluded from the scope. Cost information was requested on power plants that had already started operation between the years of 2018 and 2021.

The cost analysis covers investment costs and operation and maintenance costs. The two categories were further subdivided into cost components, and respondents were asked about them in the questionnaire (Table 1). Questions were also posed on information for use in cost analysis (the plant’s installed capacity, etc.).

Table 1: Cost components

Investment costs	
	Development and design costs
	Ground preparation costs (including tree felling)
	Solar PV modules
	Inverters
	Mounting systems
	Cables, junction boxes, and other materials
	Installation costs
	Transforming equipment and installation costs
	Grid connection costs
	Other costs
Operation and maintenance costs	
	Daily operation management and monitoring costs
	Weed removal
	Regular inspection costs (including legal inspections)
	Accident response / repair costs (including reserves for this purpose)
	Insurance costs
	Land leasing fees

Overview of the data

The data obtained from the questionnaire is summarized below (Table 2). In total, 62 sets of cost data were collected. Most of the data, 52 sets, was from medium-size power plants (system withcapacity between 50 kW and less than 2,000 kW). The total installed capacity of all plants surveyed was 93 MW. The installed capacity of utility-scale power plants was highest, approximately 57 MW of the total, and the average capacity of these plants was 14 MW. The installed capacity of medium-size power plants, which provided the most data sets, was around 36 MW, and their average capacity was 694 kW. Solar PV plants tend to have solar cells in excess of their installed capacities. Overall, the plants had solar cells with generating capacity of 123% of their installed capacity (below, this ratio is called the "inverter load ratios (ILRs)"). The ILRs was highest at small-size power plants (267%). At medium-size plants and larger, the ratio was around 120% on average.

Table 2: Overview of data collected

	Total	Small-size	Medium-size	Utility-scale
Valid data sets	62	6	52	4
Installed capacity (kW)	93,359	255	36,104	57,000
Average installed capacity (kW)	1,506	42	694	14,250
Solar cell generation capacity (kW)	114,702	680	43,508	70,514
Inverter load ratios (ILRs)	123%	267%	121%	124%

Note: Small-size plants are system with under 50kW. Medium-size plants are system with capacity between 50kW and less than 2000kW, and Utility-scale are system with capacity 2000kW and over.

As can be seen, the installed capacity of the plants (AC capacity) differs from the installed capacity of their solar PV modules (DC capacity). This is why, in the following analysis, when discussing the unit price per kilowatt, it is necessary to clarify whether the prices being discussed are per unit of plant capacity or per unit of solar PV module capacity. As shown above, overloading is the standard practice regardless of the plant's size, and solar PV module, mounting system, installation, and other costs are closely proportional to solar PV module capacity (DC based). For this reason, unless otherwise indicated, the study's analysis uses the unit cost as per solar PV module capacity (kW DC).

1 Characteristics of Investment Cost Structure

1.1 Trends in investment costs

First, investment costs in recent years have generally been declining, with 2020 as the exception (Fig. 1). In 2018, plants with investment costs of over 200,000 yen per kilowatt were the majority, but in 2019, plants with costs under 200,000 yen increased, and in 2021, costs fell to around 150,000 yen. From the above, it can be seen that investment costs are trending down. In 2020, there is large variation in the data that is characterized by a broad distribution of investment costs, from extremely high to low.

Regulatory changes made by the government is potentially one of the reasons for the higher investment costs in 2020. The Agency for Natural Resources and Energy in 2018 introduced new rules aimed at plants not yet in operation. The rules mandate that plants certified under the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities ("Renewable Energy Special Measures Act") between fiscal 2012 and fiscal 2014 must promptly begin operating if they are not yet in operation and have not set a deadline for doing so. While the deadlines differed somewhat depending on the plant's size, the rules mandated that operations start by the end of 2020.[1] It is possible that there was a last-minute rush by the aforementioned plants to begin operating in 2020. In fact, in the sample data obtained by the questionnaire, a conspicuously high percentage of plants that launched in 2020 were certified between fiscal 2012 and fiscal 2014.

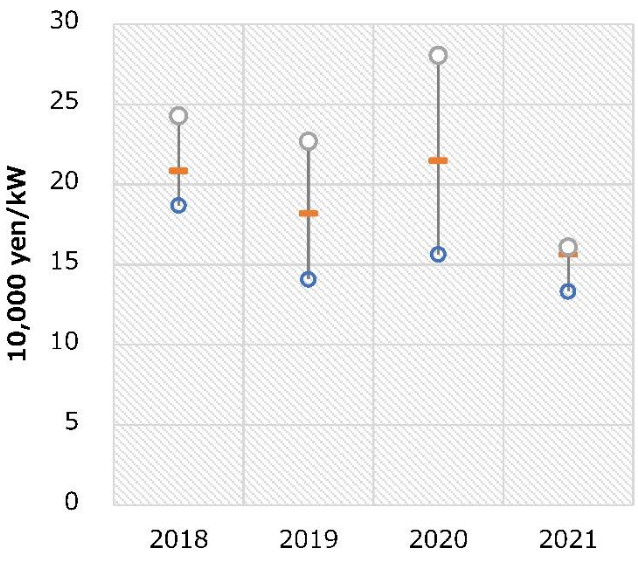

Fig. 1 Investment cost annual trend

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

Next, looking at individual cost items, the unit costs for solar PV modules, mounting systems, and transforming equipment and installation have been falling across the board, except in fiscal 2020 (Fig. 2). Installation costs have also been declining. At the same time, other facility costs and ground preparation costs have been rising slightly, while inverter costs, development and design costs, and grid connection costs were unchanged.

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[1] According to "New Measures on Non-operation of Approved Facilities for Photovoltaic Power Generation under the Feed-in Tariff (FIT) Scheme (Summary of Revisions)" issued by the Agency for Natural Resources and Energy in 2018, the deadline for applicable facilities to begin operating was March 31, 2020 for plants less than 2 MW, September 30, 2020 for plants of 2 MW or more, December 31, 2020 for plants subject to regulatory assessment.

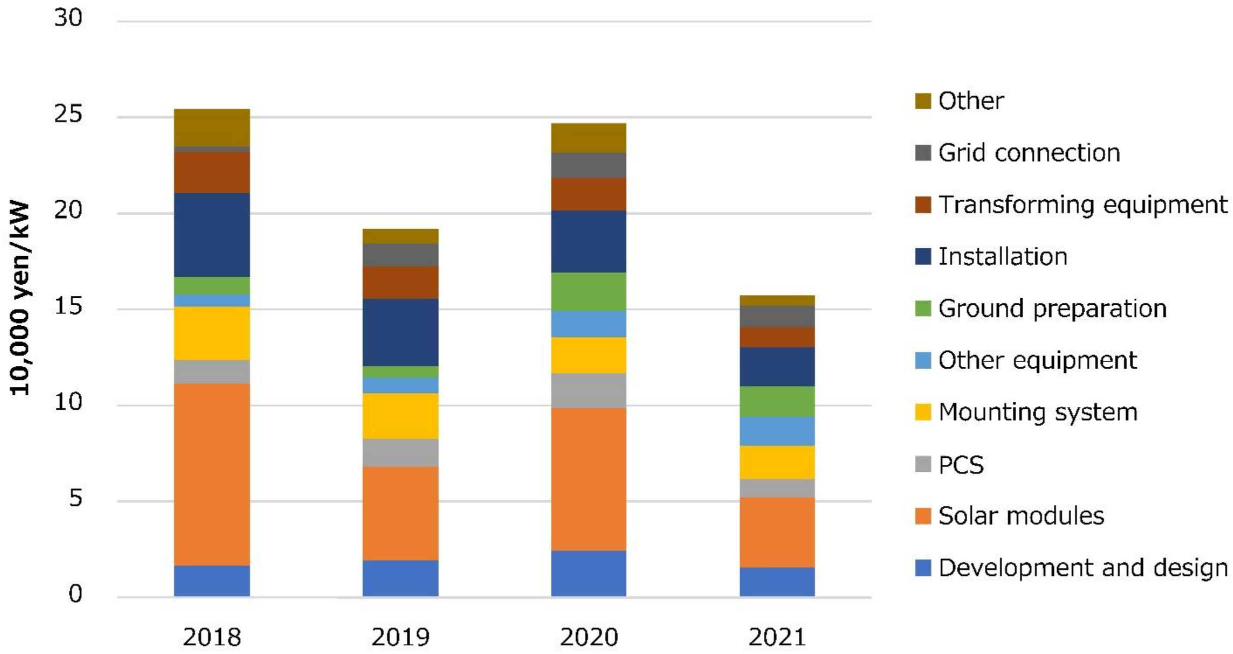

Fig. 1 Average unit price by cost item

1.2 Solar PV module costs

Solar PV module costs account for the largest proportion of total investment costs. As shown in Fig. 3, module unit prices have been declining markedly. In 2018, the median price was around 60,000 yen /kW, but in 2021, it was approximately 30,000 yen/kW, so the cost has fallen by roughly half.

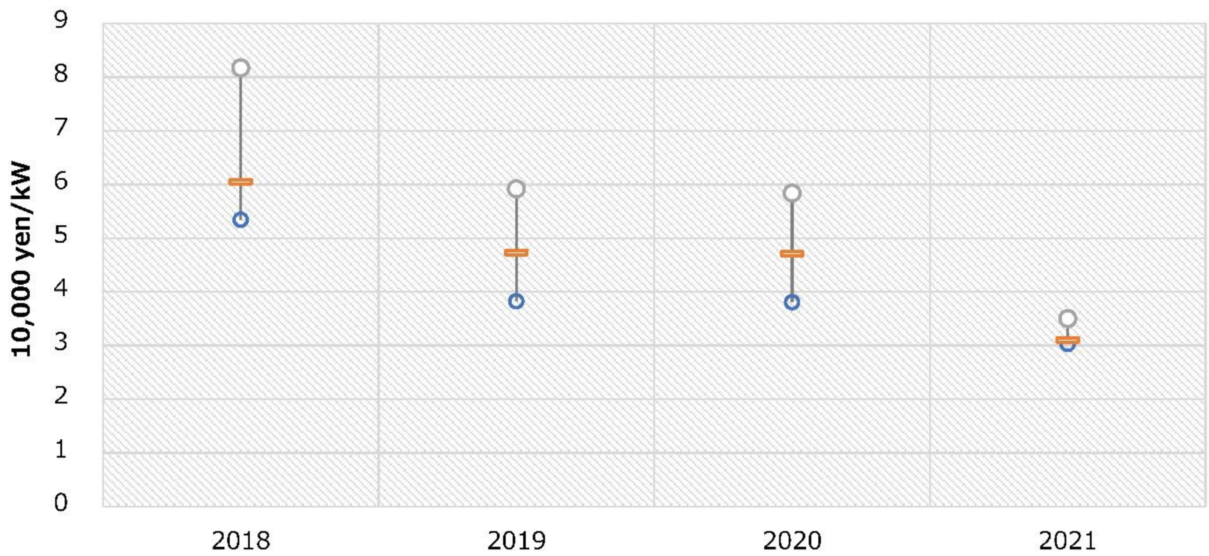

Fig. 3 Unit prices for solar modules

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

Fig. 4 shows solar PV module shares by manufacturer region. As can be seen, Chinese and Taiwanese manufacturers account for nearly half the market. Japanese manufacturers have a 36% share. Looking at module unit costs by manufacturer, Chinese and Taiwanese modules have the lowest unit costs, with a median price of 42,000 yen/kW (Fig. 5). Unit costs for modules from Japanese manufacturers, however, are the highest, with a median price of 56,000 yen/kW. As a characteristic of Japanese modules, extremely high-priced modules are used in some cases, with per-kilowatt prices in excess of 200,000 yen.

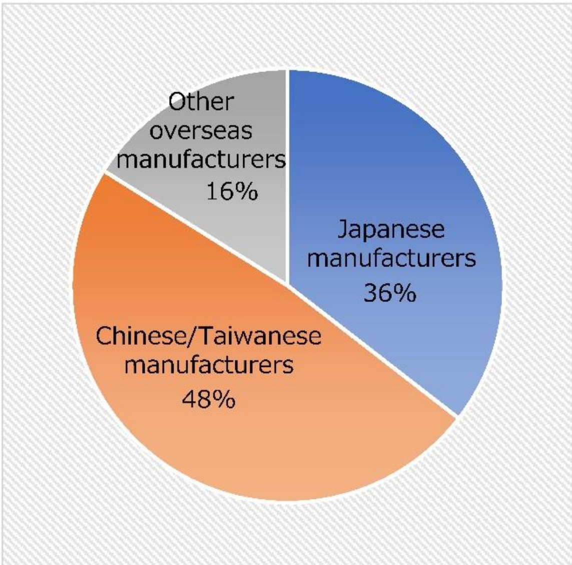

Fig. 4 Share by manufacturer region (number of power plants)

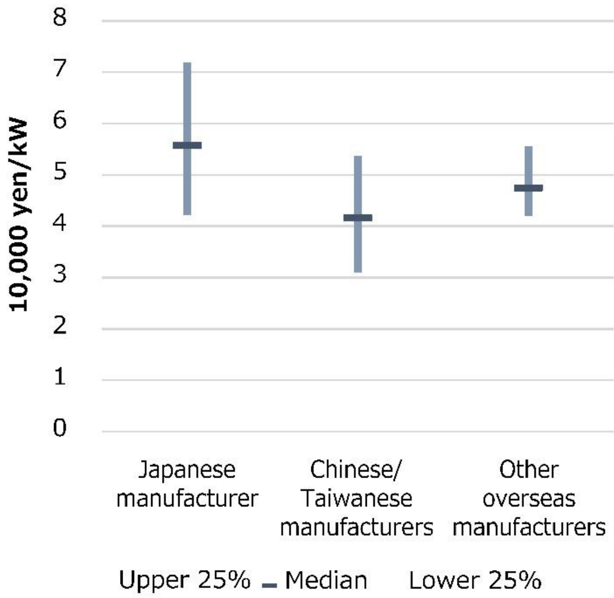

Fig. 5 Module unit costs by manufacturer region

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

1.3 Inverter costs

Overall, there have been no consistent changes in inverter costs over time. Large variations were found in cost, as exemplified by a widening gap between the 25th and 75th percentiles from 2019 to 2020 (Fig. 6). Based on the median value, costs increased greatly in 2020 and then returned to their previous level in 2021. This trend is prevalent with medium-size power plants, which has a large sample size, and costs have also been decreasing at small-size and utility-scale power plants. The high costs in 2020 are potentially due to the regulatory factors discussed above (see Footnote 1).

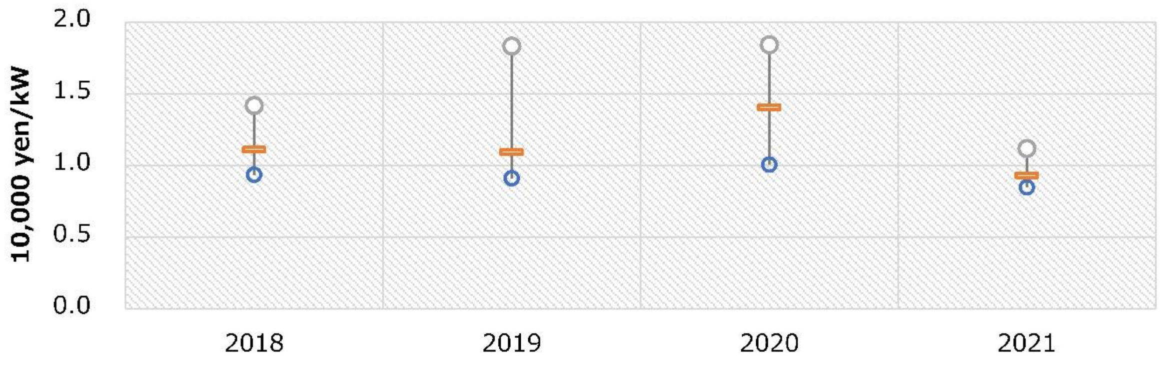

Fig. 6 Trends in inverter unit prices (quartiles)

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

1.4 Mounting system costs

Mounting system costs have been consistently decreasing. The median cost has fallen from around 30,000 yen/kW to around half that in 2020, around 15,000 yen/kW (Fig. 7).

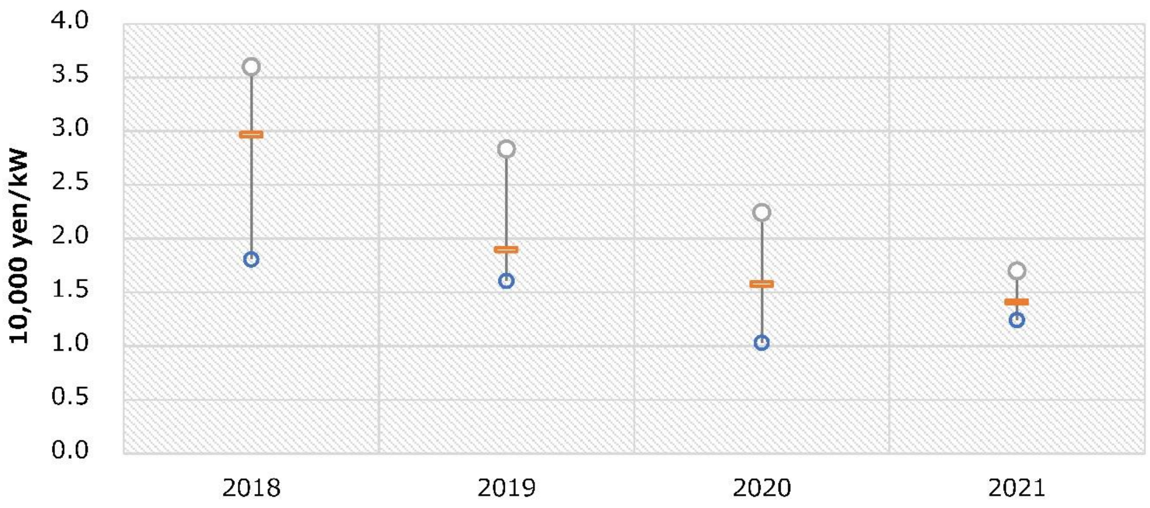

Fig. 7 Trends in mounting system costs (quartiles)

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

As shown in Fig. 8, mounting systems can be classified into four main types. Their unit costs are shown in Fig. 9, and it can be seen that the ground screw and ramming methods are the least expensive, while concrete is the costliest.

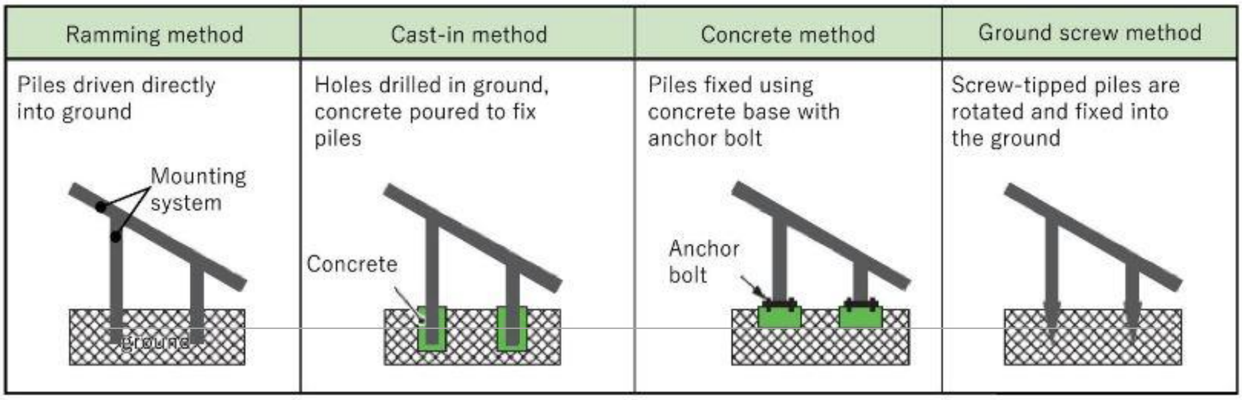

Fig. 2 Typical mounting system designs and installation methods

Source: Inaba and Watanabe (2012), "Trends in Photovoltaic Power Generation Systems and Toshiba's Approach," Toshiba Review, Vol. 67, No. 1

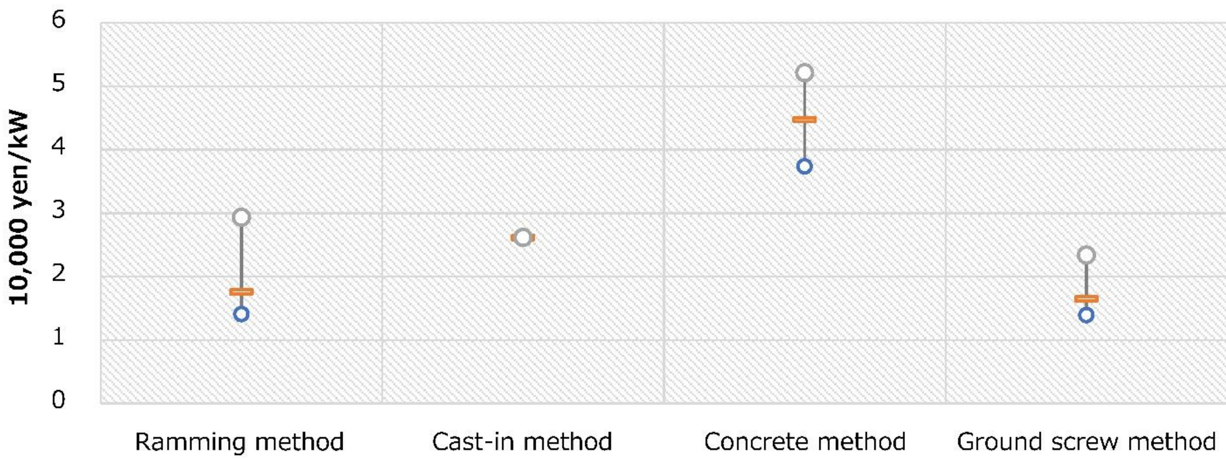

Fig. 9 Mounting system unit costs by type (quartiles)

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

Mounting system design, however, has a major impact on installation difficulty and man-hours, so when thinking about overall investment costs, it would be premature to evaluate based on the mounting system unit cost alone. When installation costs are viewed by mounting system type, concrete is the least expensive system (Fig. 10). At the same time, there is substantial variance in the ground screw method. The 75th percentile has plants with costs close to 40,000 yen/kW, while in the 25th percentile, the installation unit cost is approximately 10,000 yen/kW, which is the same level as the concrete method. Therefore the cost variance is nearly fourfold even within the same method.

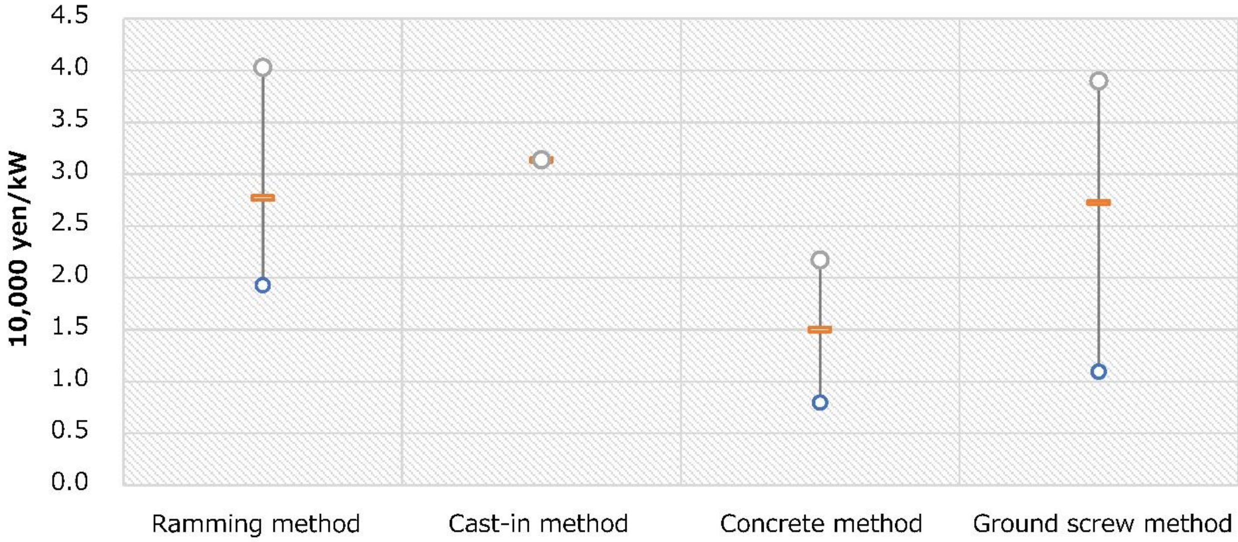

Fig. 10 Installation unit costs by mounting system type (quartiles)

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

In light of the above, mounting system unit costs combined with installation unit costs are defined as installation-related costs, and these costs were analyzed. Mounting system unit costs and installation unit costs both change substantially, so construction-related cost averages are shown for each year (Fig. 11). There appears to be no clear advantages among the methods, but the ground screw method tends to be relatively inexpensive. Next are the ramming method and concrete method. The sample size for the cast-in method is minimal, so its cost trends are difficult to evaluate.

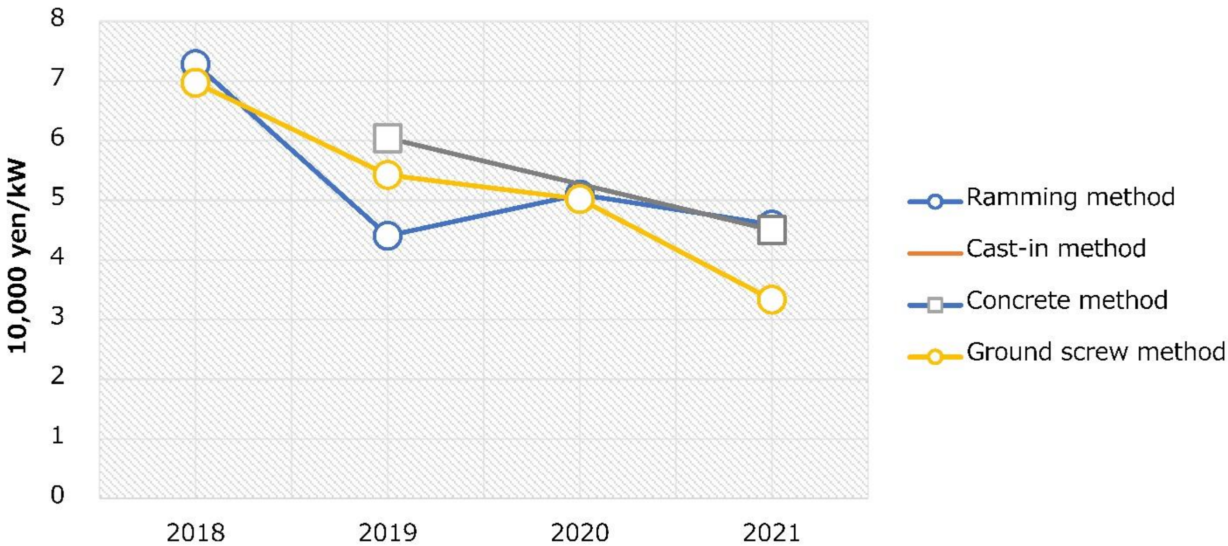

Fig. 11 Trends in installation-related costs by mounting system type (averages)

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

1.5 Grid connection costs

Grid connection costs vary significantly due to a range of factors. The factors believed to have a major impact on grid connection costs are the voltage level connected and the distance to the connection point. We compared averages for the three voltage classes, small-size, medium-size, and utility-scale, and the results are shown in Fig. 12. As a general trend, the higher the voltage class is, the higher the grid connection cost per kilowatt.

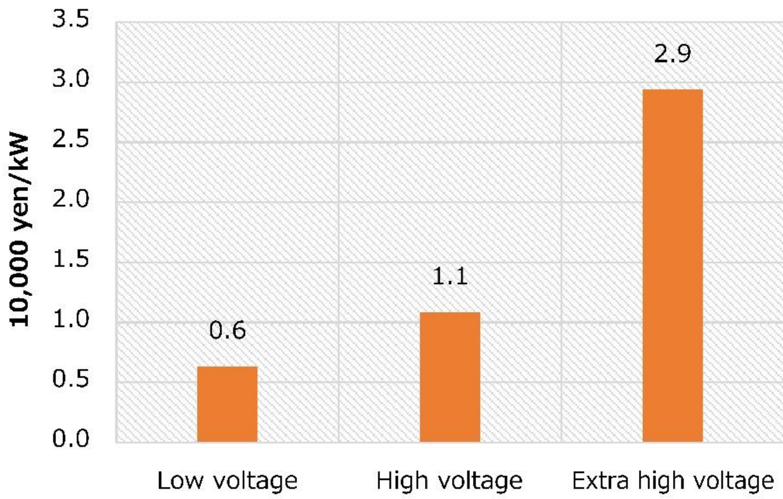

Fig. 12 Average gird connection cost by voltage class

Looking at these trends in grid connection costs, the costs for medium-size plants, which have a large a sample size, are generally increasing (Fig. 13). However, as can be seen in the data from 2019 to 2021, there are large discrepancies in the costs themselves. This suggests that grid connection costs largely depend on individual site characteristics. Though this being the case, the 25th percentile and the median value continued to rise from 2018 to 2021, so, overall, it can be concluded that grid connection costs are increasing.

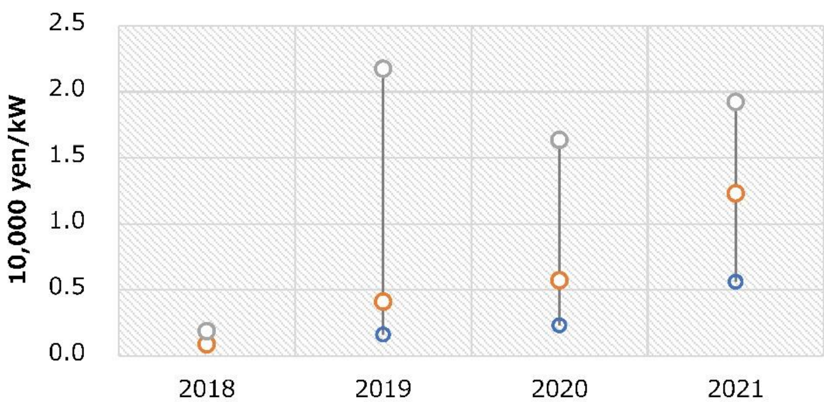

Fig. 13 Grid connection costs at medium-size plants (quartiles)

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

Next, we look at the relationship between grid connection costs and distance for medium-size plants. Fig. 14 shows the relationship between connection costs and connection distance, and it can be seen a weak correlation (simple correlation coefficient R=0.44).

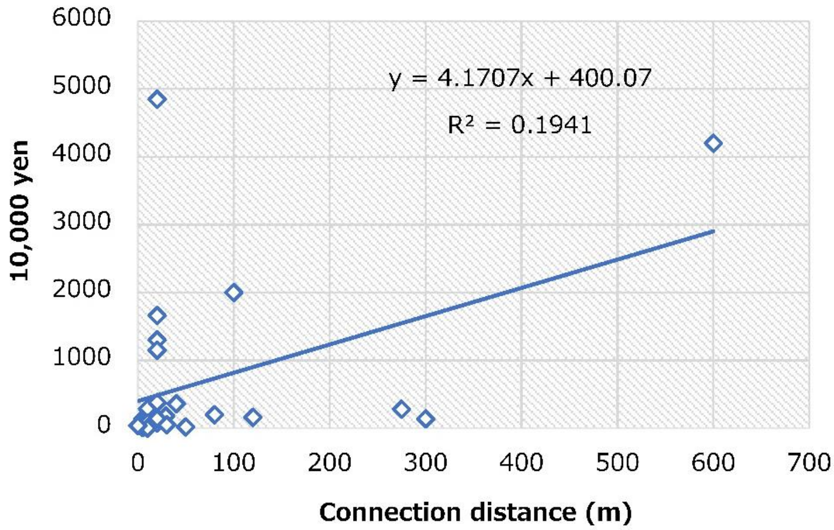

Fig. 14 Relationship between grid connection costs and connection distance at medium-size plants

Finally, we look at grid connection costs based on who installed the connection. Typically, the plant operator contracts construction to a transmission and distribution operator, pays electricity charges, and has the power lines installed. In some cases, however, the plant operator builds the power lines to the connection point itself. Fig. 15 shows construction costs by contractor at medium-size power plants. Connection costs per meter, as it can be seen, are lower when the plant operator does the constriction work itself than when it contracts the work to a power company.

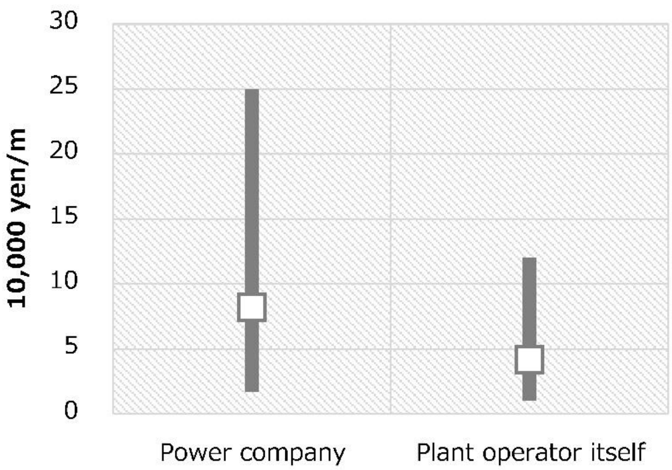

Fig. 15 Comparison of connection unit costs (10,000 yen/m) at medium-size plants

2 Factors Impacting Investment Costs

The previous chapter analyzed investment costs based on various factors. In this section, we look at other factors that potentially impact investment costs. This was taken up in the 2019 report, and it will be looked at again here.

2.1 Investment costs by certification year

First, there are differences in investment costs by the certified fiscal year under the Renewable Energy Special Measures Act. In Japan, there are differences in procurement price depending on the fiscal year the plant was certified under the Renewable Energy Special Measures Act. The procurement price between fiscal 2012 and fiscal 2014 was between 32 yen/kWh and 40 yen/kWh, and the price in fiscal 2020 was 13 yen/kWh (or less), so substantially lower. These differences in the procurement price could be having an impact on investment costs.

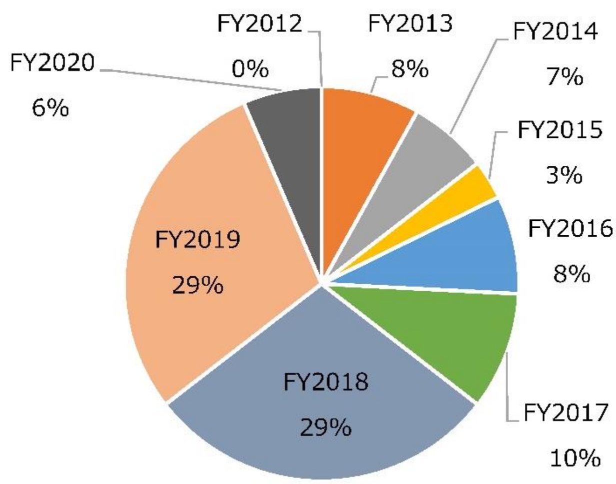

Fig. 3 Percentage of sample plants by fiscal year of certification

As shown in Fig. 16, 15% of the plants in this year's sample were certified in the initial period of the Renewable Energy Special Measures Act, between fiscal 2012 and around fiscal 2014. Most of the plants in the sample, 58%, were certified in fiscal 2018 or fiscal 2019.

This looks at the relationship between the procurement price and investment costs. We took the average investment cost for each procurement price category and looked at the correlation between this average and the procurement price. The simple correlation coefficient was 0.567, indicating a correlation (Fig. 17). This suggests the possibility that procurement prices are impacting investment costs.

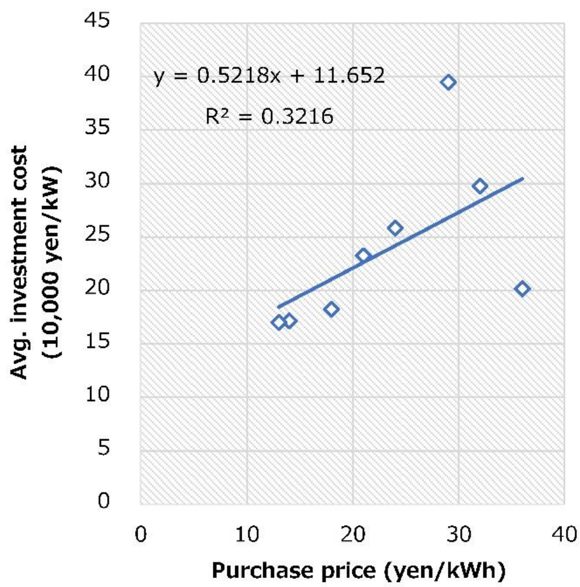

Fig. 17 Correlation between investment cost and procurement price

2.2 Investment costs by contract type

Secondly, we analyze differences in investment costs from the type of contract. Depending on the contract type, there are different degrees of management and involvement of the plant operator in design, procurement, construction, and so forth, which is why the type of contract has the potential to impact the cost.

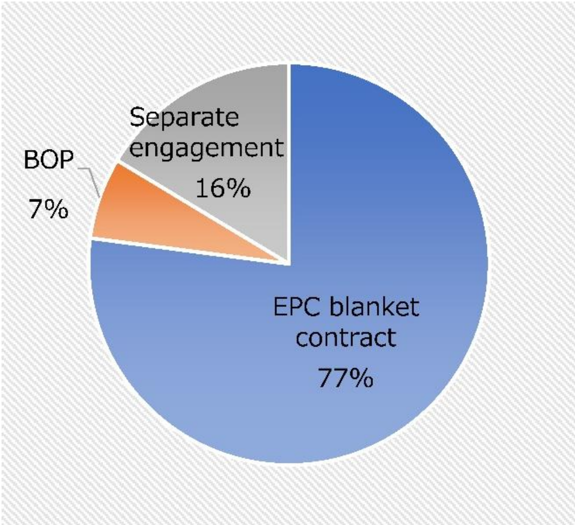

Fig. 4 Percentage by contract type

There are three basic ways in which design, procurement, and construction are carried out for solar PV plants. The first is contracting to a primary contractor (EPC contractor) to undertake the entire project, design, procurement, and construction. This method is called EPC blanket contracting. The EPC contractor is contracted to handle system design, material procurement, arrangement of various subcontractors, and supervision of construction. The second method involves the plant operator procuring the primary materials for the plant and then contracting other work—detailed design, construction, etc.—to another contractor. This is called a BOP arrangement. The third way solar PV plants are built is by the plant operator conducting design, procurement, and construction in-house and then selecting and contracting companies separately when outsourcing. This is referred to as “separate engagement.”

Comparing investment costs by the different contract types, as was the case in the 2019 report, investment costs tend to be higher with EPC blanket contract and lower with the BOP and separate engagement approaches (Fig. 19). In particular, almost all projects with investment costs of 200,000 yen or greater were contracted via EPC blanket contracting. However, even with the EPC method, at the 25th percentile, there are cases of projects with investment costs equivalent to the separate engagement method, which represents a slight change from the situation in the 2019 report.

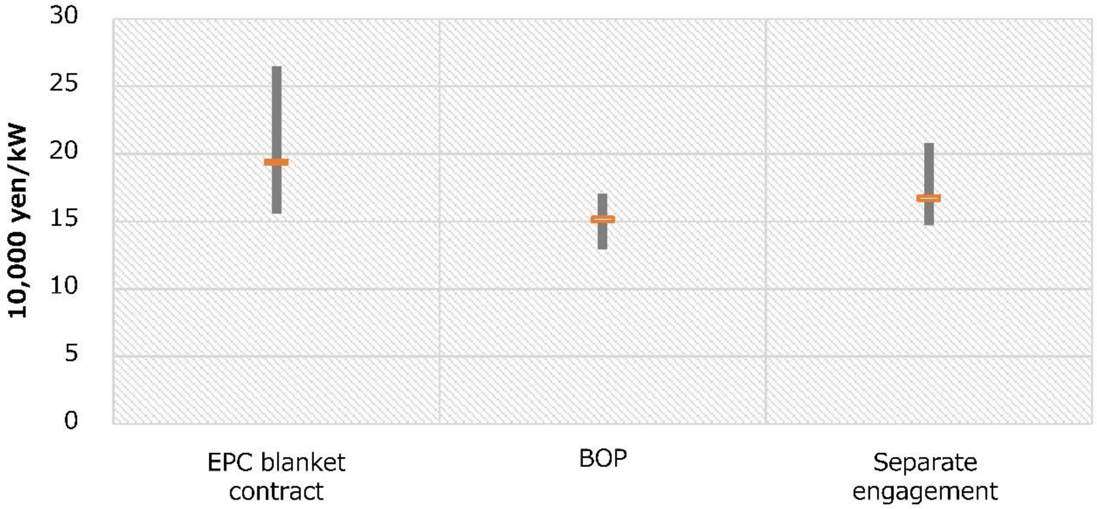

Fig. 5 Investment cost by contract type: quartiles

Note: The bar graph shows quartiles from 25% to 75%. The gradient lines in the graph denote median values.

3 Structure of Operation and Maintenance Costs

3.1 Operation and maintenance cost by plant size

Operation and maintenance costs are greatly impacted by the plant's size. Compared to medium-size and larger plants, small-size plants have high average operating and maintenance costs per kirowatt (Fig. 20). However, there is no major difference in average operation and maintenance costs between medium-size and utility-scale plants.

Subdividing the costs we can see that the cost per kilowatt tends to be lower in larger size plants, except for lease fees and daily operations management and monitoring costs (Fig. 21).

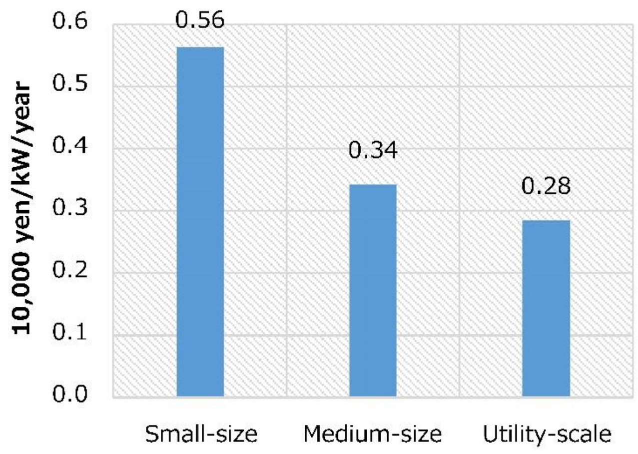

Figure 20: Average Operation and Maintenance Costs by Plant Size

Regarding daily operations management and monitoring costs, the reason there is no difference in impact between medium-size and utility-scale plants is believed to be due to the cost of appointing a dedicated chief electrical engineer, as was discussed in the 2019 report. Specifically, "Solar PV power plants generating 50 kW or greater are required under Japan's Electricity Business Act to appoint a dedicated chief electrical engineer. In particular, power plants generating 2000 kW (utility-scale) or greater are not allowed to appoint a chief electrical engineer serving a concurrent role at another power plant, nor outsource this role to a contractor—a specialist, dedicated engineer must be employed" (2019 report). As was the case in the 2019 report, it is possible that the cost of this full-time position is impacting the cost of daily operations management and monitoring at utility-scale plants.

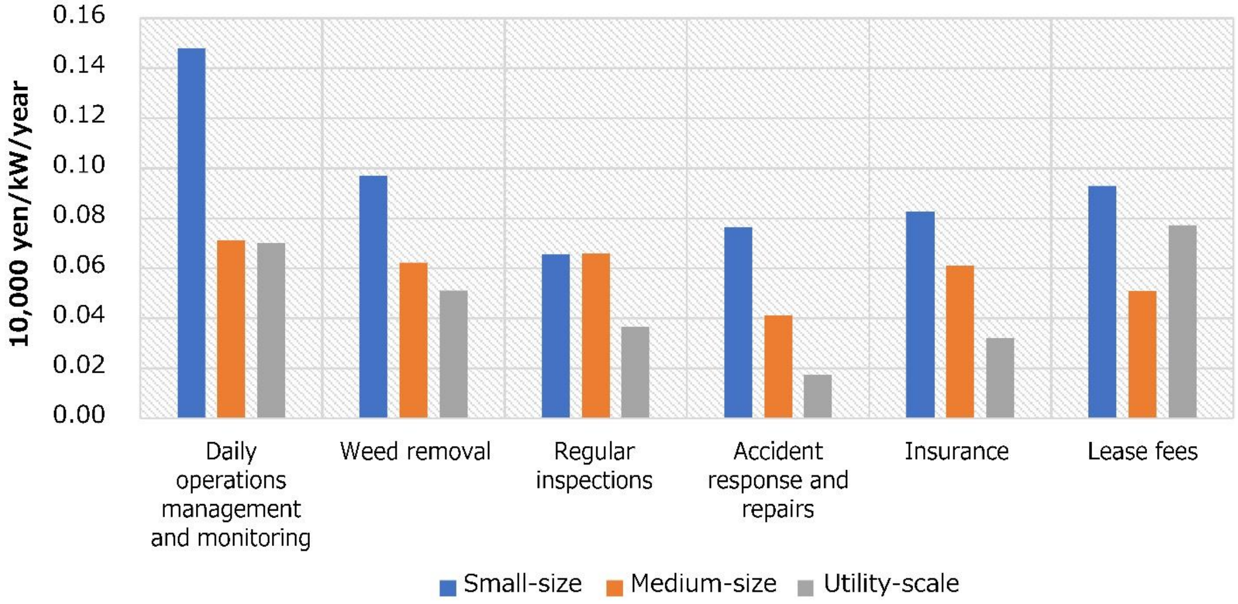

Fig. 21 Average costs by item and plant size

3.2 Changes in operation and maintenance costs over time

We next look at changes in operation and maintenance costs over time. These costs are largely impacted by the size of the plant, so changes should be considered for each size category. This report looks specifically at changes over time (averages) at medium-size power plants, which has a large sample size. As can be seen in Fig. 22, it is difficult to note any consistent trends. It could be concluded that costs have been generally flat.

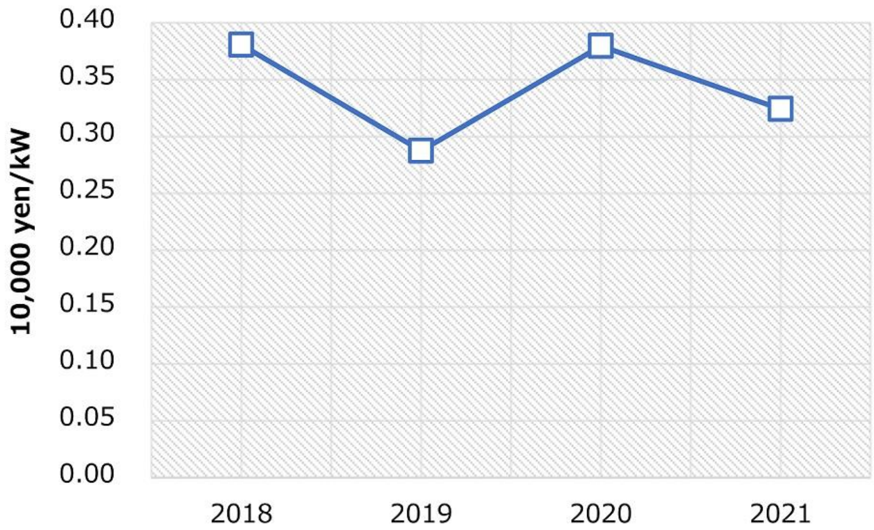

Fig. 22 Average operation and maintenance costs over time (medium-size plants)

Subdividing the costs further, the trends differ for each cost item (Fig. 23). Downward trends can be seen in insurance costs and lease fees. Insurance costs are generally proportional to investment costs, so it can be surmised that they have been declining as investment costs have fallen. It is unclear from the data though why lease fees are decreasing. There has been no changes in the trend for daily operational management and monitoring costs, regular inspection costs, and weed removal costs. Costs have trended upward for accident response and repair costs (including reserves). It is standard practice to record accident response and repair costs, but it can be seen that in 2018 and 2019 almost no costs were recorded. Since 2020, these costs have been recorded or paid at a rate of 600 yen/kWh/year. This study is unable to determine whether the increase beginning in 2020 is due to actual expenditures or reserves being set aside.

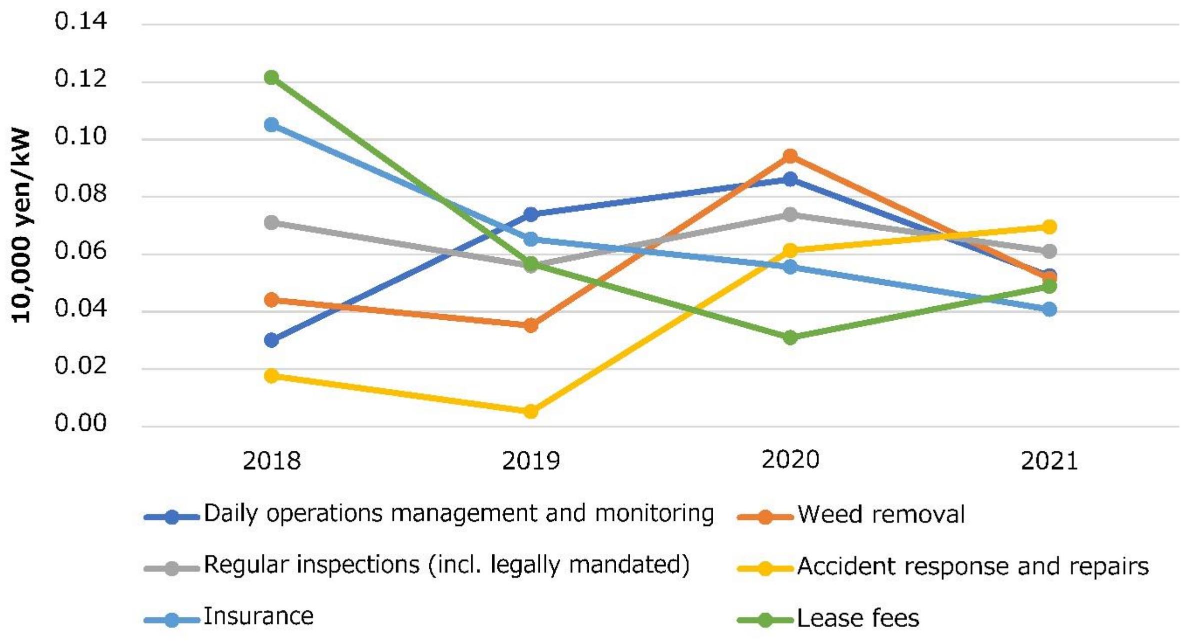

Fig. 23 Average operating and maintenance costs by item over time (medium-size plants)

3.3 Operation and maintenance costs by certification year

For operation and maintenance costs as well, we considered whether the certification year is having an effect on the costs; which is to say, whether they are impacted by the procurement price. As with investment costs, we investigated the correlation between the procurement price and average operation and maintenance costs at plants with the same procurement price. The results are shown in Fig. 24. The simple correlation coefficient is 0.659, which indicates a relationship. As was the case with investment costs, operation and maintenance costs are higher at plants with high procurement prices.

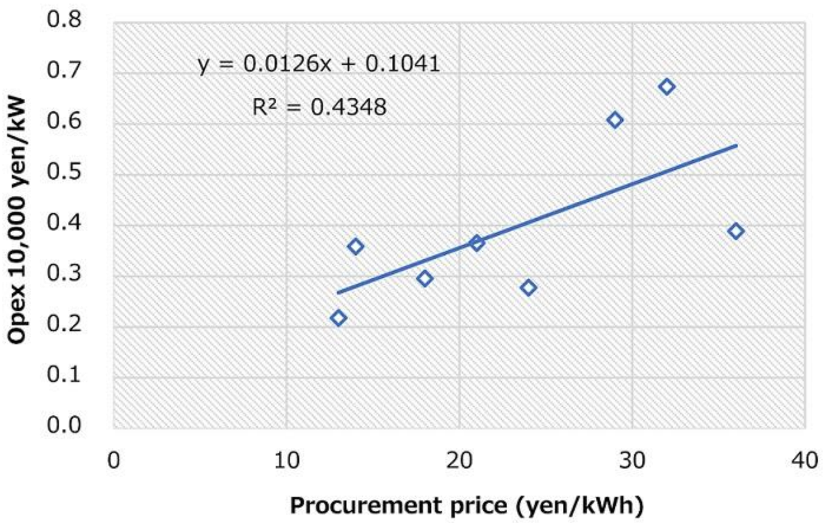

Fig. 24 Average operation and maintenance costs by procurement price

Summary of Analysis Findings

This cost study was conducted as a follow-up survey to the cost questionnaire of solar PV operators conducted in 2019. The analysis methods also generally follow the methods used in the 2019 report. The findings of the study, rather than overturning the findings of the 2019 analysis, generally reinforce the 2019 report's conclusions.

Investment costs for solar PV generation have been decreasing over time. It is clear the unit costs for solar PV modules, which account for the highest proportion of investment costs, have been decreasing over time. Installation costs and mounting system costs are also decreasing, and it is possible that installation techniques have been progressing each year. At the same time, inverter costs have been flat, a trend that differs from the findings of the 2019 report, but 2020 was likely impacted by regulatory factors. It was also found that grid connection costs have been increasing slightly. This potentially suggests a decrease in sites with favorable grid connection conditions.

Regarding the factors governing investment costs, we considered the impact of the procurement price under the Renewable Energy Special Measures Act and the impact of the contract type. As a result, a correlation was found between the level of procurement price and investment costs. Investment costs were also seen to change depending on the contract type. In particular, with EPC blanket contracting, investment costs tend to be higher. However, even with the EPC approach, at the 25th percentile, there was no difference with the separate engagement approach.

Regarding operation and maintenance costs, it is clear that they are affected by the size of the plant overall, but utility-scale plants do not enjoy scale benefits with respect to operational management and monitoring costs. As explained in the 2019 report, it is possible that the cost of hiring full-time chief electrical engineers is still having an impact. There are no clear trends in the changes in operation and maintenance costs over time, but it is possible that they have been flat. As to other factors governing operation and maintenance costs, the study again found a connection to the level of procurement price.

Based on the above, solar PV generation costs are decreasing with the continued decline in investment costs. At the same time, the possibility that the procurement price is affecting cost levels, as found in the 2019 report, was reconfirmed in this study. It is possible that the rise in investment costs in 2020 in particular is being additionally affected by the operation start deadline that was set in 2018 by the Agency for Natural Resources and Energy. Further, it is impossible to ignore the impact of the cost of full-time chief electrical engineers. These points are regulatory impacts, and changing the regulations would likely help lower costs.

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Renewable Energy Institute
11F KDX Toranomon 1-Chome, 1-10-5 Toranomon, Minato-ku, Tokyo 105-0001　TEL：03-6866-1020

info@renewable-ei.org
www.renewable-ei.org/en