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Cost and Technology Trends for Onshore Wind Power in Japan

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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.

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1 Introduction

Problem recognition and study objectives

Japan has declared its commitment to carbon neutrality by 2050 and positioned renewable energy as “decarbonized power sources under practical use” in its 6th Strategic Energy Plan (2021), stating that it will “address maximum introduction of renewable energy as major power sources on the top priority” in 2050. In addition, in the government’s 2030 energy supply-and-demand forecasts that were released at the same time, renewable energy is projected to account for approximately 20% of primary energy supply and 36-38% of total electricity generated.

Onshore wind power is a promising energy source that will be indispensable to the firm achievement of carbon neutrality in Japan, and promoting its spread and improving its economy are key challenges. Installed onshore wind capacity in Japan is approximately 5 GW at the end of 2021[1], and in the long-term energy supply-and-demand forecasts, it is projected to increase to around 16 GW by 2030 (in the “enhanced policy responses” scenario). Even so, onshore wind power would still only account for 3% of electricity generation as forecast for 2030. Further promotion and expansion are needed.

At the same time, according to the government’s Power Generation Cost Verification Working Group, onshore wind power costs are calculated at 21.6 yen/kWh in 2014 and 19.8 yen/kWh in 2020, so cost reductions have made almost no progress (Power Generation Cost Verification Working Group, 2015; 2021). 2030 generation costs are estimated at 9.9-17.2 yen/kWh, which is a wide range, and this suggests a high degree of uncertainty.

Generating costs for 2030 were estimated by applying reduction rates for construction costs used by international institutions in their declining cost scenarios (Figure 1) to Japan. The international price convergence case was also taken up to consider the possibility of even lower costs. Cost factors other than construction costs were left unchanged from 2020.

Figure 1 Approach to 2030 Onshore Wind Power Cost Reduction Forecasts

Source	Item	Recent costs	2030 costs (reduction rate 10-47%)
IRENA ‘Future of wind’, 2019 13P	Total installation costs *Average or average range	1,497 USD/kW (2018)	800-1,350 USD/kW (REmap Case 2030 costs)
Regular report	Connection costs excluded from investment costs	347,000 yen/kW (2018-2020)	**184,000-312,000 yen/kW (Construction cost estimate)**

Source: Power Generation Cost Verification Working Group (2021)
Note: “Regular report” means actual domestic cost data of onshore wind power plants reported by wind power generators under the obligation required by Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities (Renewable Energy Special Measures Act).

[1] According to Japan Wind Power Association (JWPA), accumulated installed capacity of wind power in Japan was 4.58GW at the end of 2021. （https://jwpa.jp/information/6225/）

The method used by the working group to consider costs is one possible approach, but given the gap between costs internationally and costs in Japan, taking only the rate of reduction as proportional is an approach that requires further verification. The assumptions, too, for capacity factor are “limited suitable sites” and “unchanged from 2020 in light of recent years’ trends,” but in terms of a method for 2030 capacity factor assumptions, this methodology seems to lack technical basis.

Given this background, it is important that we appropriately assess technical trends from recent years and evaluate future cost forecasts while better grounding them technologically and economically. By assessing costs based on technological and economic evidence, it becomes possible to gain insights for reducing onshore wind power costs in Japan.

Based on this recognition of the problem, this study considers possibilities for reducing onshore wind power costs in Japan by accurately grasping the technologies and economy of onshore wind power plants which have started operation since 2016. The first chapter summarizes the results of a survey of technologies. The second chapter summaries the results of an investigation and analysis of costs. The study concludes with a summary of analysis results and discusses the potential for cost reductions.

Scope and methodology of technology and cost considerations

The scope of cost considerations focuses on investment costs and capacity factors. Investment costs are divided broadly into turbine costs (e.g., nacelle, tower, blades)[2], construction costs, electric work costs, grid connection costs, and development costs. This study excludes development costs like wind condition surveys and environmental assessments, and focuses specifically on installation costs, performing detailed analysis of turbine costs, construction costs, electrical work costs, and grid connection costs. In addition, while it is important to consider operation and maintenance costs, many of the wind power plants installed after the introduction of the feed-in tariff (FiT) scheme have not been operating long, so it is difficult to acquire adequate data. As a consequence, these costs were excluded from the scope of the survey.

In terms of the methodology used for technology and cost considerations, a questionnaire was administered to wind power operators, information collected on onshore wind turbine technologies and costs, and statistical analysis performed based on the data. The scope of wind power plants was commercial plants of 1.5 MW or higher launched in 2016-2021.

The collected data is broadly divided into five categories: 1) information on the time from the plant’s FiT certification to the start of construction and the start of operations, 2) basic plant information (installed capacity, turbine capacity, number of turbines, turbine technical data), 3) information on direct construction costs, 4) information on construction (foundation, site preparations, facility installation, electrical work, transmission lines), and 5) capacity factors.

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[2] When referring to power sources in general, the term "wind power" is used. When referring to wind turbines (including nacelles, towers, etc.) and the cost, "wind turbine" and "wind turbine cost" are used. And when referring to the entire facility including electrical equipment, etc. in addition to wind turbines, "wind power plant" is used. When indicating that the facility is limited to onshore use, "onshore" shall be appended.

2 Onshore wind power technology trends in Japan

2.1 Summary of data

The data sample covers 32 power plants with total installed capacity of 646 MW and 266 turbines (Figure 2). This represents around 40% of the installed capacity of power plants built in Japan between 2016 and 2021. The average plant size is 20 MW. The average plant size around the world differs with the region, but according to Wang (2021), it is 268 MW in Central and South America, 218 MW in North America, and 24 MW in Western Europe (2019-21). The average plant size in Japan is at the same level as Western Europe.

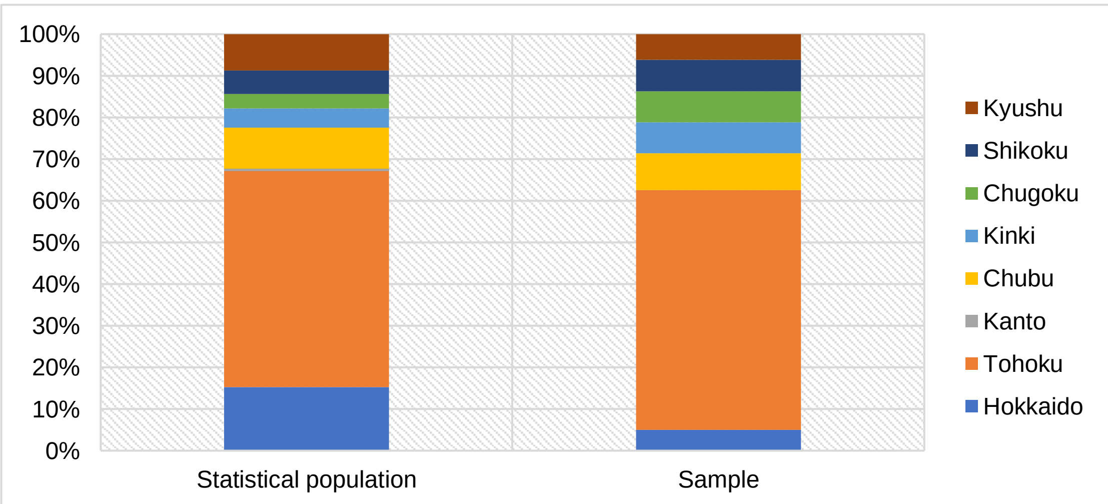
Figure 2 Summary of Power Plant Data

Launch year	2016-17	2018-19	2020-21	Total
Number of plants	7	16	9	32
Installed capacity (MW)	155	243	249	646
(Ref: Newly installed capacity in Japan MW)*	412	523	727*	1,662
Number of turbines	77	101	88	266
Avg. turbine capacity (MW/turbine)**	2.0	2.4	2.8	2.4
Avg. plant size (MW)	22	15	28	20

* Newly installed capacity in Japan: numbers calculated based on the data of Renewable Energy Promotion Law. Data of 2021 only referred to JWPA (https://jwpa.jp/information/6225/)
** Average turbine capacity = Total installed capacity / Number of turbines

The following shows the geographical distribution of the sample. As shown in Figure 3, compared to the statistical population (all plants of 20 kW of higher installed under FiT), the sample is slightly less in Hokkaido and larger in western Japan. On the other hand, the distribution in Tohoku closely mirrors the population.

Figure 3 Regional Distribution of Population and Sample



Note: The eight regions are based on prefectural divisions and differ from general electricity transmission and distribution areas.

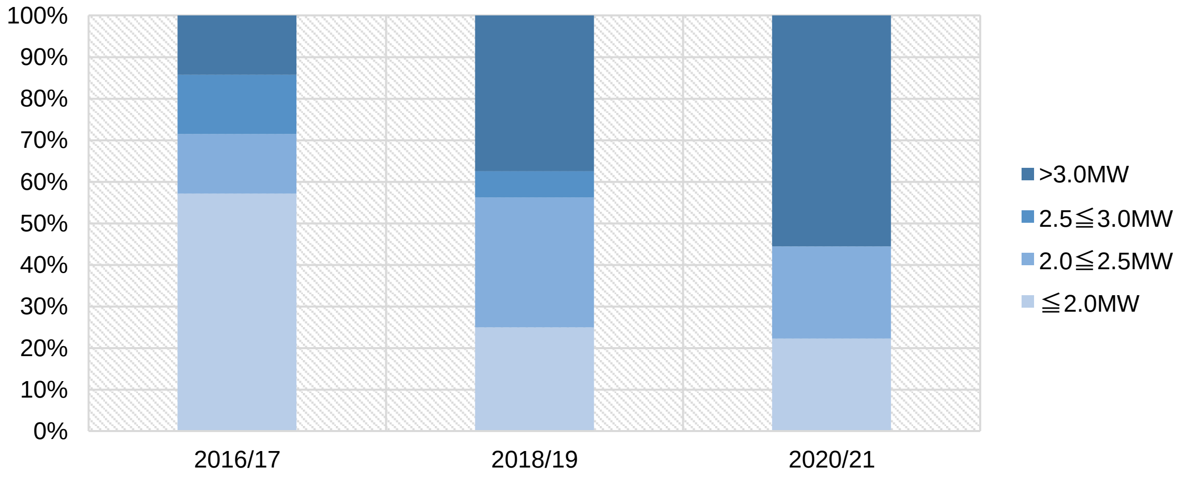
2.2 Trends in onshore turbine technologies

2.2.1 Turbine capacity

This section organizes trends in onshore turbine technologies in Japan based on the sample data. First of all, as shown in Figure 2, average turbine capacity has been increasing. It was 2.0 MW per turbine in 2016-17, and this increased to 2.8 MW in 2020-21.

Figure 4 shows the distribution of single onshore turbine capacity based on per-plant averages. In 2016-17, turbines of 2 MW or lower were the mainstream, but large turbines have been installed in quick succession so that as of 2020-21 turbines over 3 MW have become the mainstream.

Figure 4 Single OnshoreTurbine Capacity Distribution (Plant Averages)



2.2.2 Hub height and rotor diameter

As turbine capacitys have increased, hub heights and rotor diameters have also increased. The average hub height was 77.3 m in 2016-17, but in 2020-21 it was 82.4 m, advancing by approximately 5 m (Figure 5). At their highest, hub heights are over 90 m. The average rotor diameter was 85.7 m in 2016-17, but it has grown to over 100 m in 2020-21 (Figure 6). The hub height was usually designed to keep the rotor above a certain minimum ground clearance. Relation between average hub height and average rotor diameters for each year can be found that “Hub height = rotor diameter / 2 + (32~34)”. These increases in hub heights and rotor diameters have helped increase the amount of electricity generated from each turbine.

Figure 5 Average Hub Height (Plant Averages)

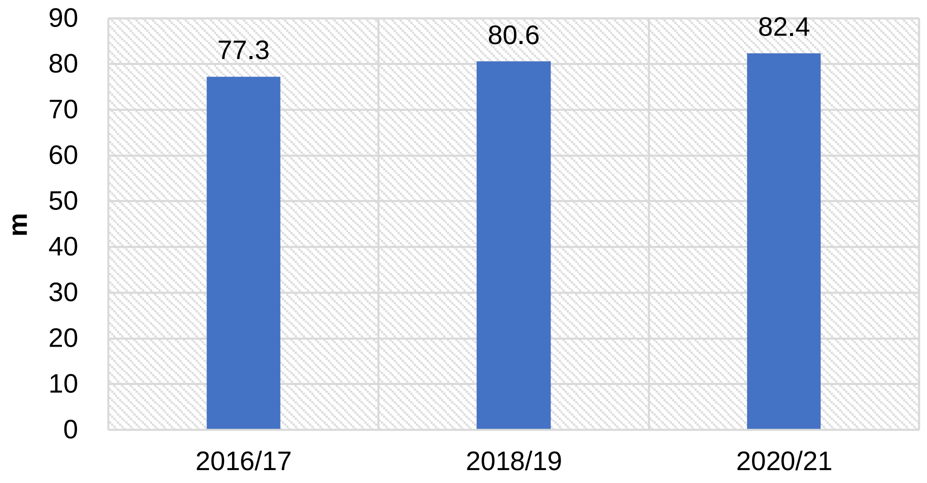
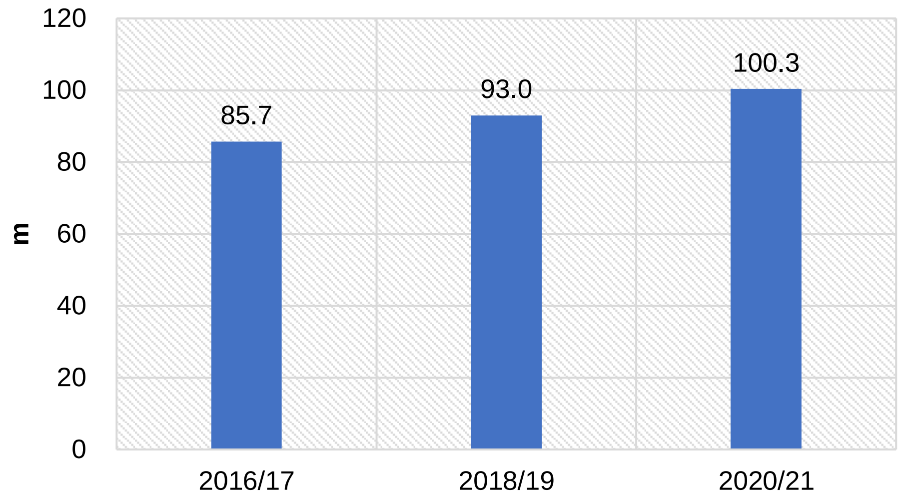


Figure 6 Average Rotor Diameter (Plant Averages)



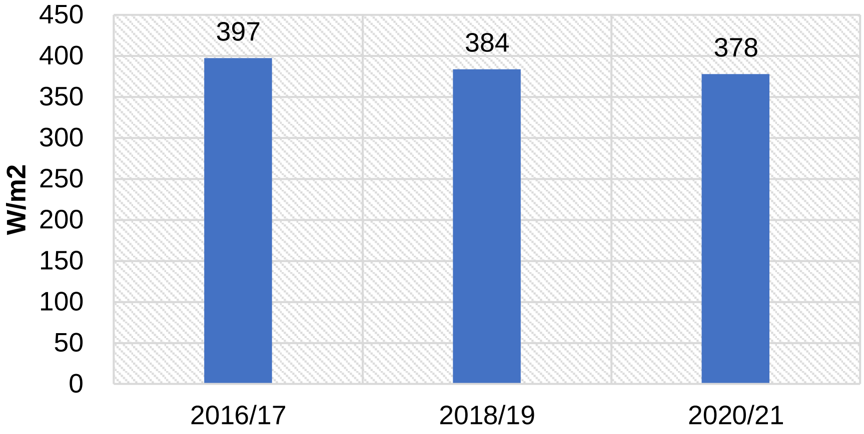
2.2.3 Specific power

On the other hand, the fact that the capacity per turbine is increasing does not necessarily indicate that the per-turbine capacity factor is also increasing, but we should looke at specific power (W/㎡), which is capacity per square-meter of swept area. Theoretically, wind power capacity (W) is proportional to the cube of wind speed and proportional to the swept area of the rotor. Therefore, for the same wind speed, the smaller the specific power (W/m2), the greater the wind power capacity (W) and the greater the capacity factor.. Generally, in areas with low wind speeds, turbines with low specific power have been used to increase the electricity generated. For this reason, to assess trends in onshore wind power technologies, it is necessary to also consider specific power figures.

Trends in average specific power in the sample obtained in this study are shown in Figure 7. There is a slight downtrend, and this, in theory, is helping to raise capacity factors. However, average specific power has decreased dramatically in the world. A slightly old data shows that specific power in the EU was already 322 W/㎡ in 2016

(IEA Wind, 2019). In Germany, specific power was 317W/㎡ (IEA Wind, 2019), and decreased to 286W/㎡ in 2021[3]. In 2021, the average rotor diameter in Germany was 133m which is significantly longer than 100m, the average in Japan. In the US, average specific power in 2020 was 223 W/m^2, which is significantly lower than Japan and Germany (DOE, 2021). The reason average specific power for onshore turbines is lower in the US is the contribution being made by the use of blades with large rotor diameters for a small single unit capacity. The average rotor diameter in the US is 124.8 m, around 25 m longer than turbines in Japan (DOE, 2021).

Figure 7 Trends in Specific Power



2.2.4 Turbine Types Based on IEC Wind Turbine Standards (2005)

IEC (International Electrotechnical Commission) is an organization that formulates international standards in the field of electrical and electronic technology and the design requirements for wind power generation are specified in IEC61400-1. Wind turbine standards based on the international IEC 61400-1[4], as shown in Figure 8. differ with differences in wind conditions and are divided into four classes, I, II, III, and S. Standard wind turbine standard are classified into three classes, I, II, and III, according to annual average wind speed, reference wind speed, and turbulence intensity. There is also a class S, which designates turbines not categorized into any of the three standard classes. “Class S designates not only turbines with high standard wind velocities specified by the designer but also potentially refers to those with low velocities and all turbines with design specifications that differ from standard, including for turbulence intensity, wind speed frequency distribution, operating temperature, and air density” (NEDO, 2008), Appendix A-3). According to Wang (2021), wind turbines classified in Class Ⅱ and Class Ⅲ have been mainly used in the world in 2016-2021.

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[3] Calculated by the average data of onshore wind power in Germany based on Deutsche WindGuard GmbH (2022)

[4] In 2019, IEC61400-1 is being revised to its fourth edition, in which a new criterion for reference wind speeds, "Class T," which considers tropical cyclones such as typhoons and high turbulence. As a result, wind turbine manufacturers have been developing wind turbines that comply with this new standard. However, all wind turbines surveyed in this study were constructed before 2019, and it is believed that the wind turbines that comply with this new standard are not included in this study.

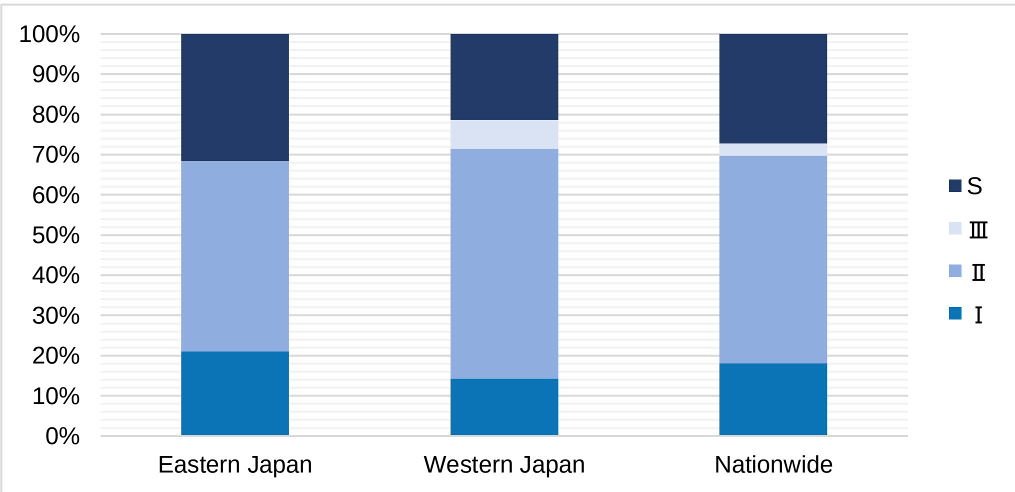
Figure 8 IEC 61400-1 (2005) Wind Turbine Standard Wind Conditions

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

Source: NEDO (2008), Appendix A-3

The turbine types in the sample data are organized based on the categories of the IEC 61400-1 standard. As shown in Figure 9, most installed onshore turbines in Japan are IEC class II turbines, followed by class S and class I. While the average annual wind speeds in Japan are lower than the rest of the world, it is expected that Class I or Class S wind turbines are required in some areas due to high turbulence intensity caused by strong winds from typhoons and the country's topography. However, this study reveals that Class II turbines, widely adopted in other countries, also account for the majority in Japan. On the other hand, Class III turbines, also adopted worldwide, are rarely used in Japan. It can be considered that Class III turbines cannot cope with the temporary strong winds caused by typhoons.

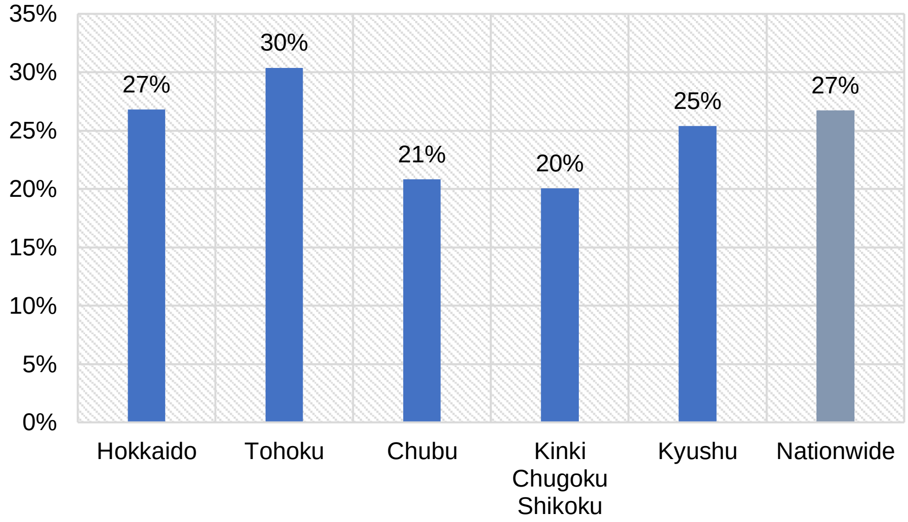
Figure 9 Distribution by IEC Standard



2.3 Capacity factor

Capacity factors were compiled for the past year, and, as shown in Figure 10, the nationwide average was 27%. Based on data from the government’s Procurement Price Calculation Committee, the average capacity factor from June 2020 to May 2021 was 26.0-27.3% (ANRE, 2021), so the 27% figure is in line with the government’s data. Looking at capacity factors by region, Tohoku and Hokkaido is higher than the nationwide average and lower in other regions, suggesting that geographically wind conditions are good in northern Japan.

Figure 10 Average Capacity Factor by Region



Note: Average capacity factor is calculated as the ratio of total estimated electricity generated by each power plant to the installed capacity of each plant.

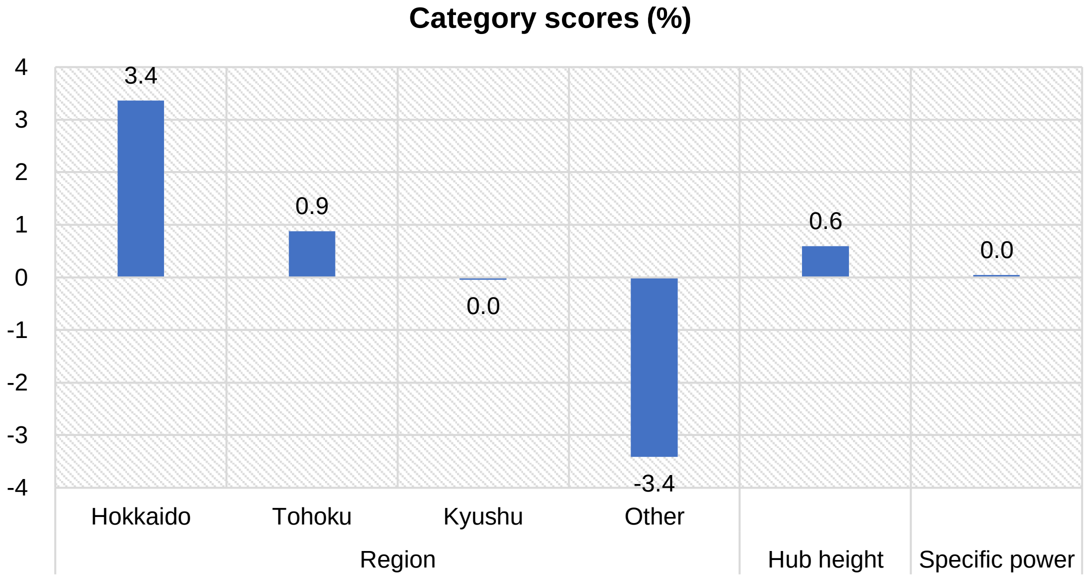
Capacity factor is impacted not only by the wind condition of the site but also by hub height and specific power. Based on this fact, we statistically analyzed the relative impact of these multiple factors on an increased capacity factor. Here, extension-type quantification I is used for multivariate analysis[5], to analyze differences in location by category. Capacity factor is the objective variable, and there are three explanatory variables: region, hub height, and specific power.

The analysis results of extension-type quantification I are shown in Figure 11. The coefficient of determination is 0.368, so analysis precision is not necessarily good. This is because the categories are roughly divided into just four regions, which does not accurately reflect wind condition at the power plant sites. Looking at category scores[6] by region, Hokkaido's score is extremely high at 3.4 points. This means that plants sited in Hokkaido have a capacity factor 3.4 points higher than the average. Regarding hub heights (m), when the height goes up by 1 m, capacity factor goes up by 0.6 points. Specific power, theoretically, should be negative, but it is slightly positive, so the low precision of the analysis is a problem.

[5] Extension-type quantification I is one of the methods to "derive a forecast model equation, predict the objective variable, and elucidate the factors that have an important influence on that prediction," and allows both quantitative and qualitative data to be applied to the forecast equation for the explanatory variables. (Institute of Statistical Analyses, Inc.)

[6] Also called categorical data, this is a quantitative representation of the extent to which each categorical item influences the value of the objective variable.

Figure 11　Analysis of Factors Affecting Capacity Factor



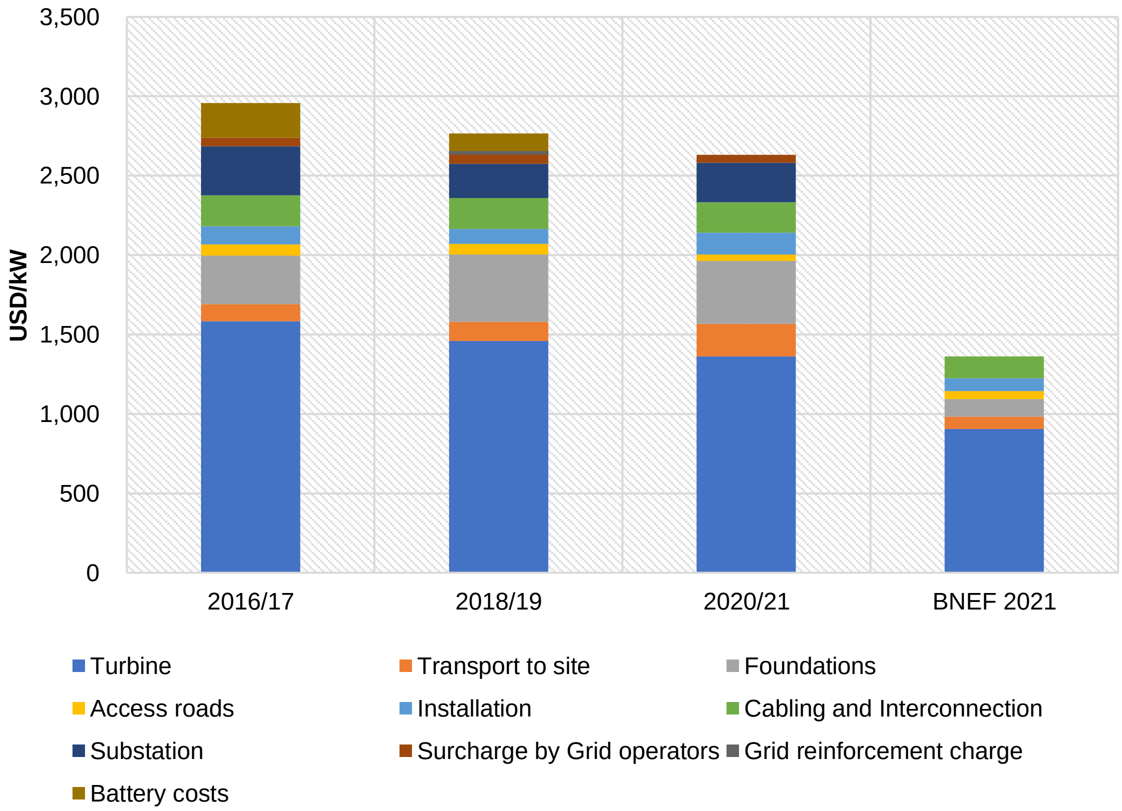
3 Trends in Onshore Wind Power Costs in Japan

Based on the analysis of technological trends in the previous chapter, we analyze onshore wind power costs in Japan in this chapter, based on the cost data that was obtained. This study focuses on installation costs. Other costs are excluded from the scope of analysis.

3.1 Installation costs

Average installation costs have been gradually coming down, decreasing from 327,000 yen/kW (2016-17) to 285,000 yen/kW (2020-21) (Figure 12). Three cost areas have been declining: wind turbine costs, electrical work costs, and battery costs. At the same time, transportation costs (domestic) and foundation and site preparation costs are increasing. Transportation costs have increased from 12,000 yen/kW to 22,000 yen/kW. However, this is due to some projects being delayed by the COVID-19 pandemic and unanticipated costs being incurred from unavoidable situations such as transport vehicles standing by or being re-dispatched. Excluding these outliers, transportation costs are nearly unchanged.

Figure 12 Average Installation Costs



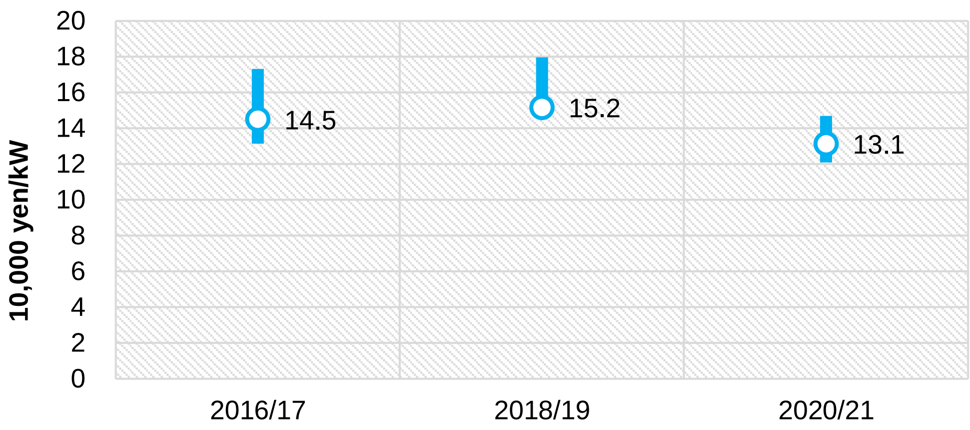
Source: BNEF 2021 refers to Wang (2021). Price of wind turbines contracted in the second half of 2020.

When compared to average installation costs for onshore wind power globally during the same period (BNEF 2021), which are 149,000 yen/kW, Japan's installation costs are fairly high (Figure 12). Looking at the breakdown, some costs differ greatly from BNEF 2021 levels and others are nearly the same. The costs equivalent to global levels are transportation costs, road development costs, and facility installation costs. The costs that differ substantially from BNEF 2021 levels are 1) turbine costs, 2) foundation and site preparation costs, and 3) electrical work and transmission infrastructure costs (including electrical work, construction work contributions, upper grid enhancements, and battery storage costs). The following considers the above three cost categories in detail.

3.2 Wind turbine costs

Wind turbine costs account for the largest proportion of installation costs, so they are an important factor for cost analysis. Average turbine costs per kilowatt have fallen from 175,000 yen/kW (2016-17) to 148,000 yen/kW (2020-21) in Japan. The median has fallen from 145,000 yen/kW to 131,000 yen/kW (Figure 13).

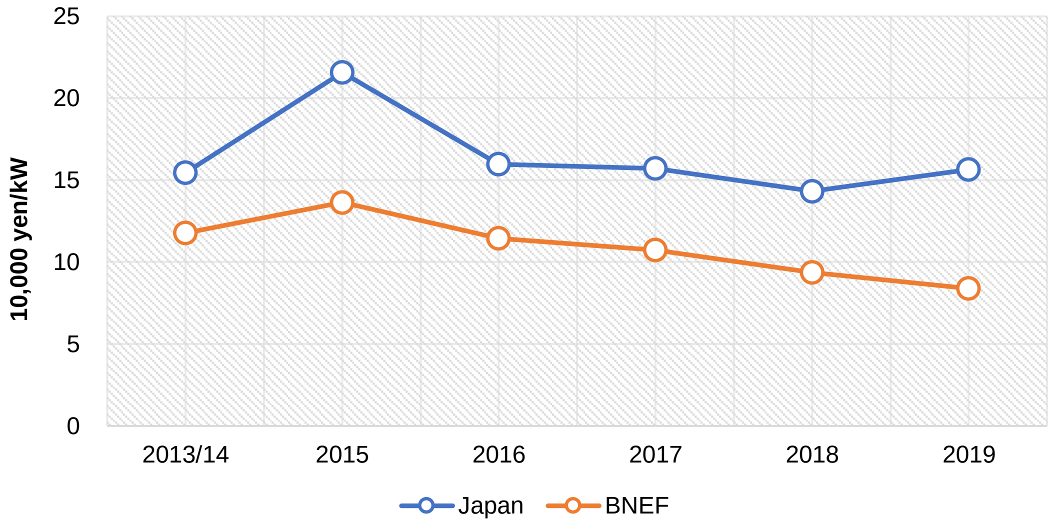
Figure 13 Wind Turbine Costs (Quartiles)



Note: The median is shown with ○; the upper-lower range is 25% and 75%.

At the same time, as shown in Figure 12, there is a major difference between turbine costs in Japan and turbine costs internationally. However, BNEF 2021 figures in Figure 12 refer to turbine prices contracted in the second half of 2020, and in some cases they are not on the same timeline as costs in Japan, which are shown based on the launch year. In order therefore to compare costs on the same timeline, for turbine costs based on the construction-start year (at site delivery time), the results of this survey and overseas data were compared (Figure 14). As a result, there was a cost difference of around 50,000 yen/kW. Around 30% of power plants adopted wind turbines supplied by relatively expensive turbine manufacturers. This cost difference was hardly reduced even if they were excluded.

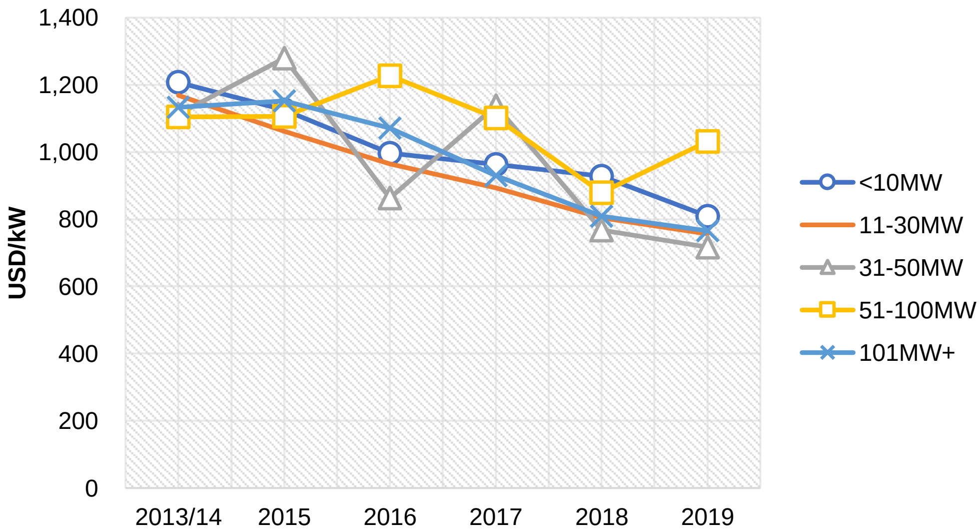
Figure 14 Turbine Costs: Comparison of Japan and International Levels



Source: BNEF applies figures in Wang (2021). Exchange rates use the average rate for that year.
Note: international transportation costs are included in turbine costs data of both Japan and BNEF.

As mentioned above, Japan's wind power plants are nearly the same size as Europe's, but differ greatly in size from the US. To determine whether this difference in plant size has a major impact on the cost of the wind turbines that are procured, reference was again made to BNEF data (Figure 15). Looking at Figure 15, wind power plants of 11-30 MW (the average plant size in Japan is 20 MW) procure turbines at costs that are equivalent to other sized plants, particularly large-scale plants. It is hard, therefore, to conclude that differences in power plant size in the world is likely to be the reason for the high cost of wind turbines in Japan. With regard to the turbines themselves, even if there are some differences in specifications (incl. IEC standards), it is unlikely that this would produce large differences in real costs between Japan and the rest of the world.

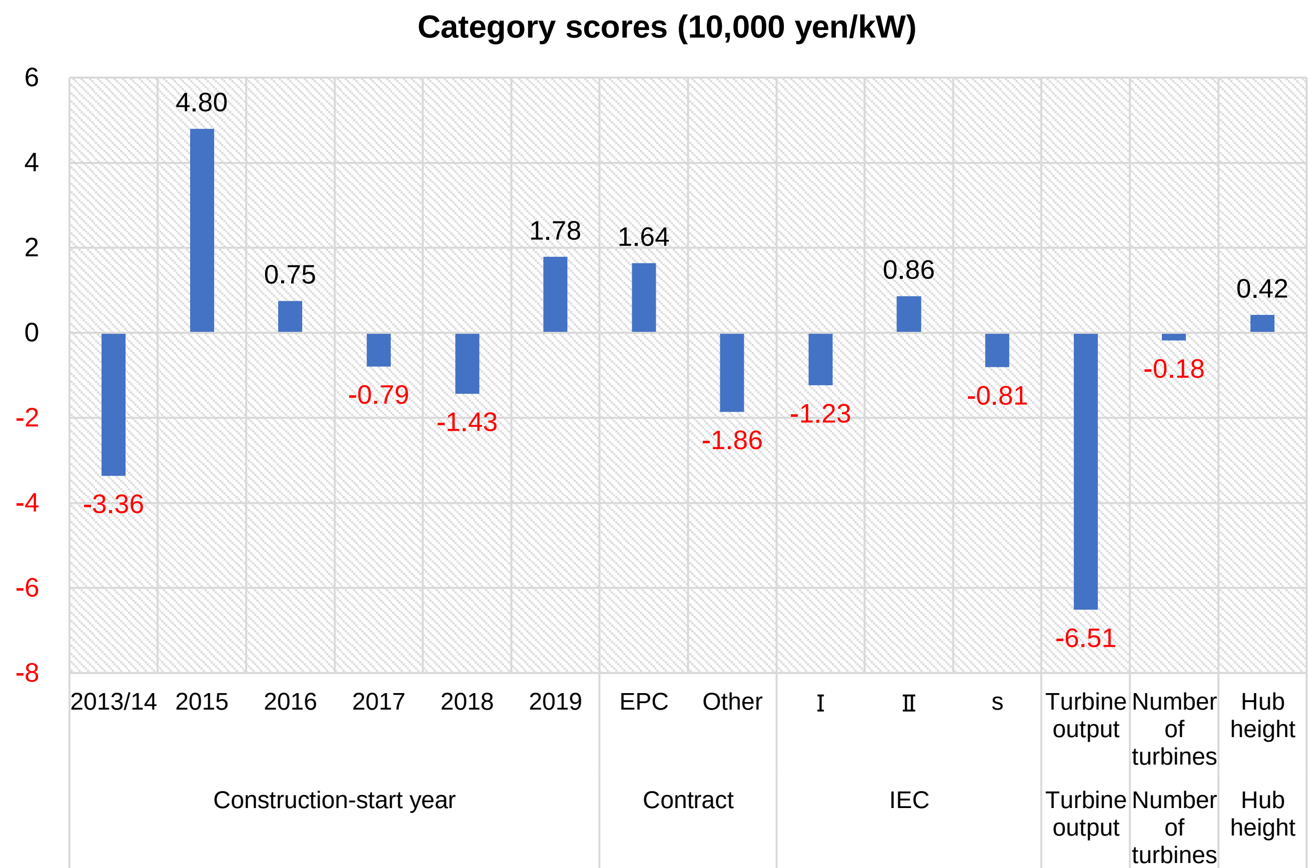
Figure 15 Turbine Cost by Plant Size (at Site Delivery Time)



Source: Created from Wang (2021).

Next, we analyze factors thought to impact turbine costs (per kilowatt) using extension-type quantification I. In this analysis, the objective variable is turbine cost, and the explanatory variables are construction-start year, contract type, IEC standard, single turbine capacity, number of turbines (at the plant), and hub height (Figure 16). The analysis resulted in a coefficient of determination of 0.537, which is medium precision. Excluding differences caused by the construction-start year, the results suggest that increasing single turbine capacity could contribute to reducing turbine costs. Differences in contract type could also be an important factor. Procuring turbines with methods other than via EPC contract (through BOP[7] or separate engagement[8]) has the potential to reduce costs. Further, increasing the number of turbines at the plant is also a cost-reduction factor. On the other hand, advancing hub heights is potentially a cost-increase factor.

Figure 16 Analysis of Turbine Cost Factors



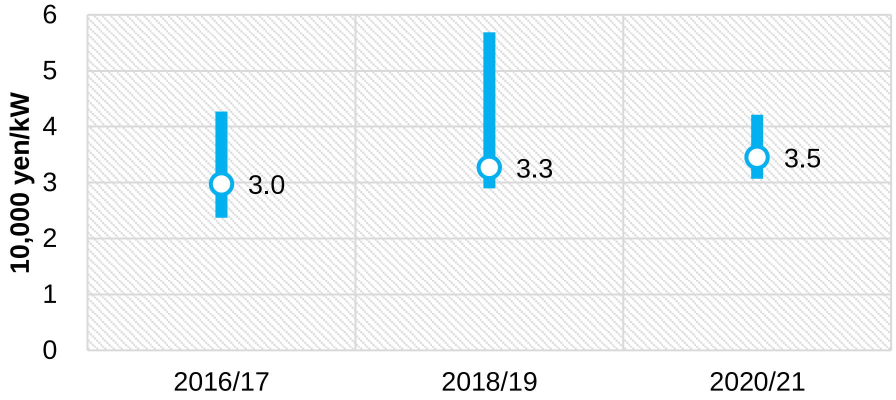
[7] BOP contract type stands for [Balance of Plant] contract, in which all the construction work is ordered to a general contractor, except for wind turbine procurement.

[8] Separate engagement contract is a method in which the power producer supervises every process from wind turbine procurement to construction work and contracts directly with each individual construction company, rather than making an order in a bundle with an EPC contractor for everything.

3.3 Foundation and site preparation costs

Average foundation and site preparation costs have increased from 34,000 yen/kW in 2016-17 to 43,000 yen/kW in 2020-21. The median has also increased slightly, from 30,000 yen/kW to 35,000 yen/kW.

Figure 17 Foundation and Site Preparation Costs (Quartiles)



Foundation and site preparation costs could be impacted by the site topography and construction material costs. Firstly, the study looked at topography and construction details, factors that could correlate with foundation and site preparation costs. Figure 18 shows the average site prep soil volume per turbine, pile foundation rate, and average single turbine construction costs for each topographical type. Each of these items is related to foundation and site preparation costs. Topography is categorized into four types based on topographical data for wind power plant sites in the Environmental Impact Assessment Database System[9] maintained by the Ministry of the Environment in reference to the 1:200,000 topographical map prepared based on the Fundamental Land Classification Survey administered by the Ministry of Land, Infrastructure, Transport and Tourism. Site prep soil volume is related to costs for preparing the yard. Also, classified broadly, there are two types of foundations, direct and pile, and even the same plant may use both types depending on ground conditions; foundation and site preparation costs also vary.

Figure 18 Construction Details and Unit Costs by Topography Type

Topography type	Number of plants	Avg. site prep soil volume per turbine (1,000 m^3)	Avg. pile foundation rate	Avg. single turbine construction costs (million yen/turbine)
Lowlands	11	2.3	90%	161
Tablelands	5	2.1	67%	100
Hills	4	8.1	83%	65
Mountains	13	5.3	48%	86

Note: Pile foundation rate: Number of turbines with pile foundations / Number of turbines at the plant

[9] Ministry of the Environment, "Environmental Impact Assessment Database System" (https://www2.env.go.jp/eiadb/ebidbs/)

Based on topography type, the following characteristics can be found. First of all, with regard to site prep soil volume per turbine, soil volume is low on plains and tablelands, around 2,000 m^3 per turbine, but in hills and mountains, where the terrain is complex, soil volume is over 5,000 m^3 per turbine. As for the foundation construction method, pile foundations are generally used when plants are installed on soft ground. Because this cost depends on ground conditions at the site, it is difficult to find clear trends based on the topography type, but pile foundations are often used in lowlands and tablelands. On the other hand, in mountains, the direct foundation rate is relatively high compared to other topography types. Average foundation engineering costs per single turbine are high in lowlands and tablelands and relatively low in mountains and hills. The result runs contrary to the normal assumption that construction costs are high in mountainous areas.

Next, concrete is one of the construction materials that would impact the costs, so the study looked at the price of ready-mix concrete (RMC) (Figure 19). Using price indices by city for each year to calculate average RMC prices, in Tohoku (Sendai), the price has been coming down since peaking in FY2014-15, and it has been increasing in most other regions.

Figure 19 Average Ready-Mix Concrete Price Estimates by City (yen/m^3)

	Sapporo	Sendai	Tokyo	Niigata	Nagoya	Osaka	Hiroshima	Takamatsu	Fukuoka
FY2013	10,962	13,696	12,522	11,801	9,101	12,072	14,115	8,127	10,562
FY2014	12,363	14,048	12,814	12,339	10,256	12,072	14,115	8,187	10,900
FY2015	12,400	14,048	13,279	12,527	11,221	12,072	14,796	8,457	10,900
FY2016	12,896	14,020	13,279	12,527	11,098	13,171	14,929	10,867	10,137
FY2017	13,243	13,696	13,412	12,364	10,806	15,609	14,929	12,584	9,374
FY2018	13,243	13,444	13,824	8,969	10,930	16,116	14,929	12,584	11,412
FY2019	13,243	12,938	14,195	8,519	11,300	18,314	15,698	13,878	13,450
FY2020	13,243	12,390	14,408	10,247	11,300	19,400	15,950	14,800	13,450

Note: Average RMC prices by city are calculated for each fiscal year using RMC prices listed in “Primary Material Markets and Price Trends” on Kensetsu Plaza, a general construction portal site, and price indices by city by fiscal year published by the Economic Research Association.

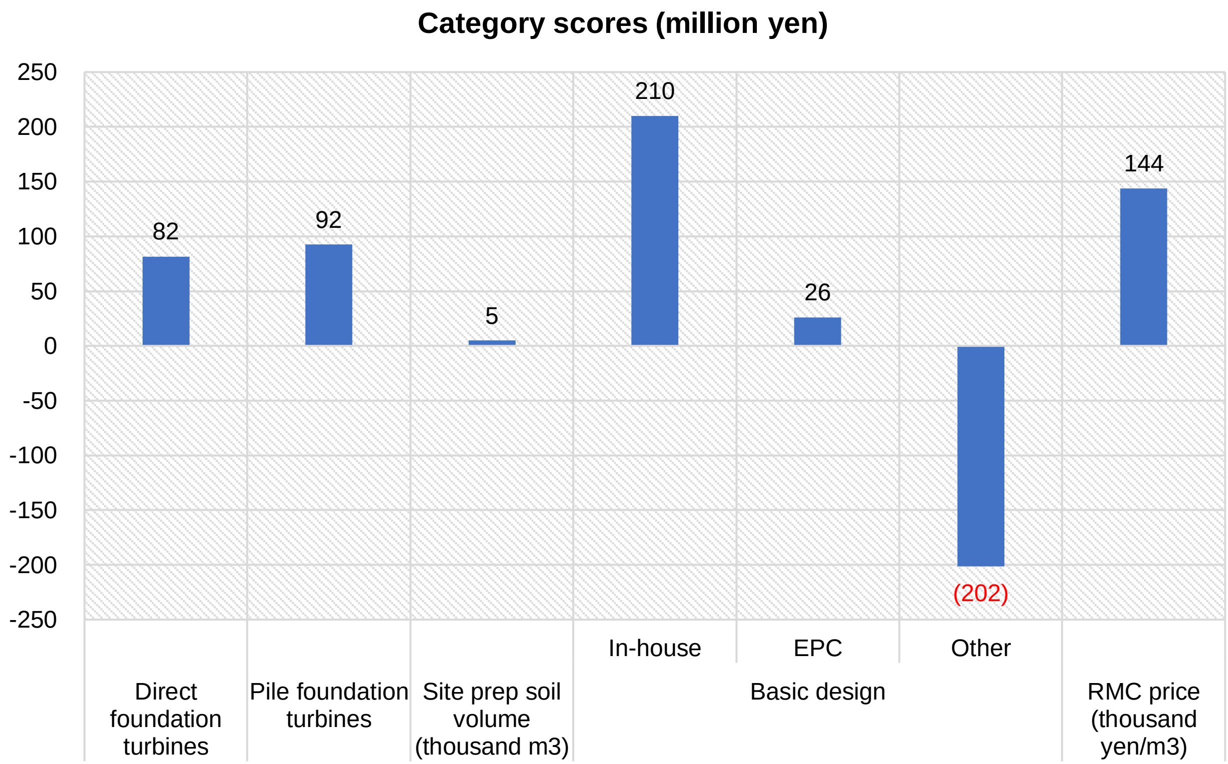
As shown above, foundation engineering costs are tied to various factors. Statistical analysis therefore was performed to determine the extent to which the multiple factors affect these costs. This method used was extension-type quantification I. The objective variable is foundation engineering costs (total) and the explanatory variables are foundation type, site prep soil volume, RMC prices, and basic design contractor[10].

The results of extension-type quantification I analysis are shown in Figure 20. The coefficient of determination is 0.648, so analysis precision is medium. From this analysis, it can be seen that foundation type has a large effect on costs. The category scores specifically indicates that pile foundations are approximately 11 million yen per turbine more costly than direct foundations (Figure 20). In Figure 18, foundation engineering costs are higher in lowlands, possibly due to the fact that in lowlands, the solid ground is several tens of meters below ground level, and

10 Basic design contractor has been added as an explanatory variable because in correlation analysis the correlation ratio exceeded 0.1.

therefore, costly pile foundations are often used. Also, it was found that both RMC prices and site prep soil volume have an impact on costs. Moreover, differences in the basic design contractor also potentially affect foundation engineering costs. Though it is unclear how differences in the contractor affect basic design, it is possible that in the basic design it is important to consider elements such as the optimal layout of turbines in terms of the impact of these on foundation engineering costs.

Figure 20 Analysis of Factors Affecting (Total) Civil Engineering Costs



3.4 Electrical work and transmission infrastructure costs

As shown in Figure 12, electrical work costs and transmission infrastructure costs are extremely high compared to overseas. These costs include installation costs for transformers and other electrical equipment, onsite cable installation costs, and installation costs for power lines from the plant to the connection point (offsite connection lines).

Moreover, there are also surcharge required to pay to the transmission and distribution system operator when connecting to the grid. In addition, when a connection request is made by power producer, if the transmission and distribution system operator determines there is no available capacity on the upper grid, the producer was also charged for upper grid enhancement costs[11]. Separate from this, some transmission and distribution operators required wind

[11] This system was changed with the "Guidelines on Grid Enhancements from Power Facility Installation and the Cost Burden, etc. of Operations" formulated in 2015, and regarding core intraregional grids in the upper two voltage categories, in terms of the general cost burden, as a basic principle, power producers bear no burden except in cases in which significant enhancement costs are incurred

power producers to take measures for frequency changes, and for this they required that battery storages be installed for some wind power plant connections. For example, in FY2008 and FY2010, before the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities (Renewable Energy Special Measures Act) was introduced, Tohoku Electric made offers to purchase electricity from wind power plants on the condition that battery storages were installed (Tohoku Electric Power Co., Inc., 2008; 2010). The survey sample included a number of plants that responded to this offer. For these plants, battery storage installation costs are included.

Figure 21 Trends in Average Electricity/Transmission Related Costs

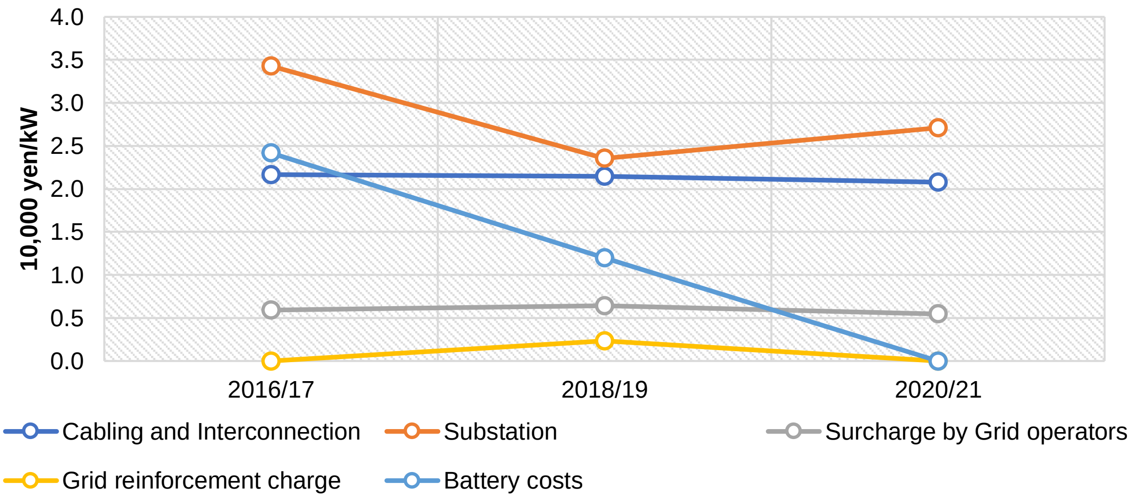


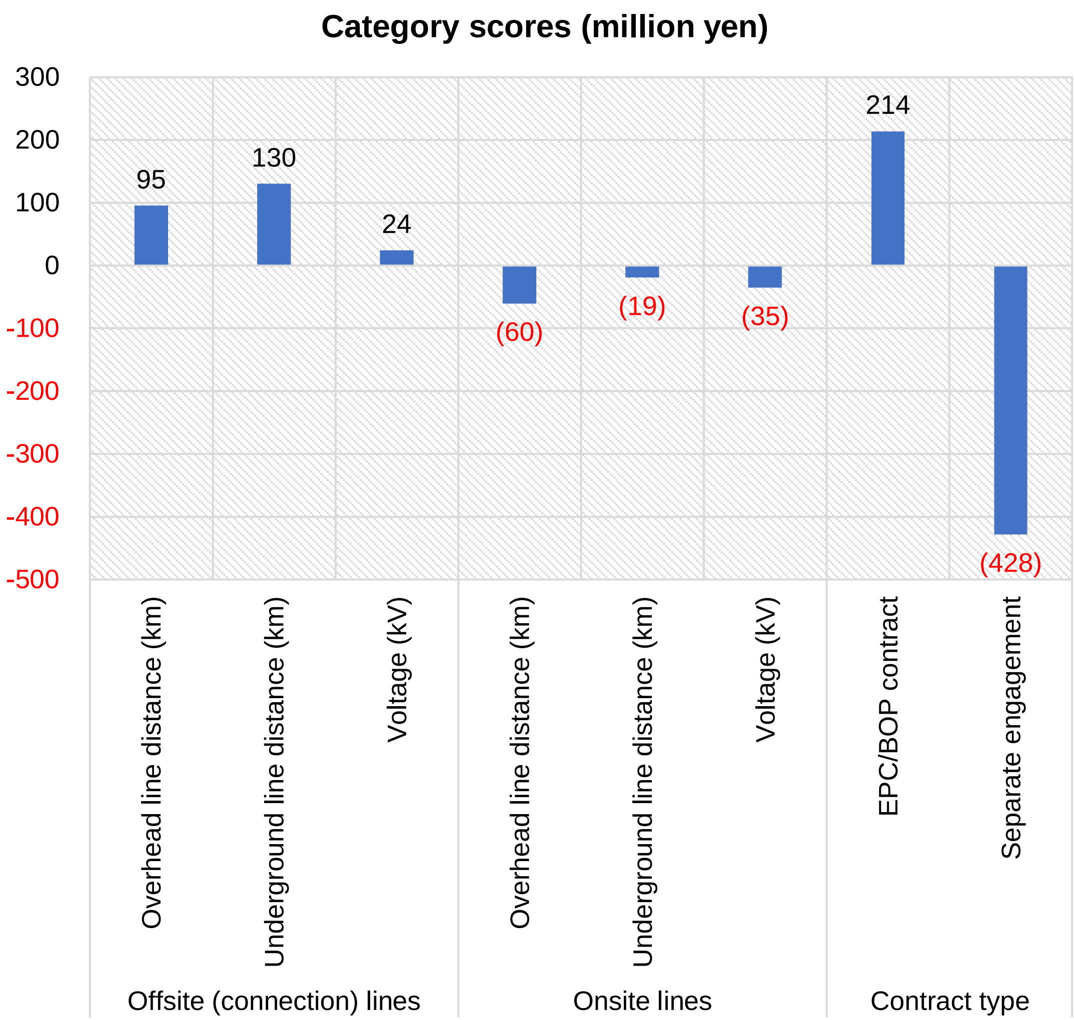
Figure 21 shows the average cost per kilowatt based on the survey sample. In terms of trends, average battery costs were 24,000 yen/kW in 2016-17, but costs dropped sharply and were zero in 2020-21. This means that there were no longer connections to the grid by power plants that had been required to install battery storages prior to the Renewable Energy Special Measures Act taking effect, as discussed above. As mentioned, battery storages were only installed at certain power plants, so it is difficult to grasp the actual situation looking at average costs alone. Taking only plants that have battery storages, battery costs exceeded 60,000 yen/kW in all cases, significantly raising installation costs. In the other cost category, electrical work costs registered a large decline in 2018-19. Regarding upper grid enhancement costs, within the sample, there was one plant that had these costs. It was a medium-sized plant with total capacity between 7.5 MW and less than 15 MW, but it bore upper grid enhancement costs of more than 200 million yen. Other costs (transmission infrastructure costs, construction work contributions) are flat and have not changed.

(when the maximum general cost burden [20,000 yen/kW for onshore wind power] is exceeded) (Agency for Natural Resources and Energy, 2015).

Transmission infrastructure costs are installation costs for onsite power lines and offsite connection lines. These costs vary with the voltage level and line length. The study used the extension-type quantification I method to analyze the relationship between these related factors and (total) transmission costs. The objective variable is (total) transmission costs, and the explanatory variables are type of offsite connection lines and onsite power lines, distance,voltage, and contract type.

As a result, the coefficient of determination is 0.784, so precision is high. As shown in Figure 22, the length of offsite connection lines, particularly underground lines, is a factor that increases costs. Underground offsite connection lines are more costly than even overhead lines, which are 30 million yen per kilometer. It was found that higher-voltage offsite connection lines lead to increased transmission infrastructure costs. However, transmission at high voltage reduces transmission loss, so it is important that cost increases are balanced out by transmission efficiency. Another noteworthy finding was differences in transmission infrastructure costs depending on the contract type. That is to say, separate engagement has the potential to reduce transmission infrastructure costs.

Figure 22 Analysis of Factors Affecting (Total) Transmission Infrastructure Costs



4 Conclusion: Summary of Analysis Results and the Potential for Reducing Onshore Wind Power Costs in Japan

This study analyzed technology trends and costs for onshore wind power in Japan over the six years from 2016 to 2021. Below is a summary of the findings gained from this study which offers insights into the potential of reducing onshore wind power costs.

1) Steady increase in wind turbine size was observed in Japan. From 2016 to 2021, the average turbine capacity increased from 2.0 MW to 2.8 MW. In particular, the output of most turbines installed in 2020-21 were over 3.0 MW.

2) Increase in turbine capacity is very much interconnected with advancments in hub heights and reducing specific power. Both of these serve to increase the capacity factor. These factors are also listed in JWPA (2019) ‘s report on Cost Competitiveness Task Force, and is considered as one of the technologies that will drive costs down in wind power generation in Japan.

3) On the other hand, JWPA (2019) also states that technological progress, such as growth in turbine size “is projected to increase construction costs even if technological innovations in nacelles, towers, and foundation structures are anticipated” and there are concerns that turbine, foundation and site preparation costs will rise. The results of this study however confirmed that although increasing hub heights was a cost-adding factor, increasing turbine capacity had the potential to reduce turbine costs (per kilowatt).

4) Regarding foundation and site preparation costs, no evidence was found that increasing turbine capacity causes an increases in costs. The results showed that pile foundation costs compared to direct foundations may have an influence in pushing up costs and that the complexitiy of the terraine was not the sole factor affecting costs.

5) The study also revealed that the voltage of the offsite connection line and the distance of the underground line were important factors that affected transmission infrastructure costs. Taking this into account when installing power lines will be worthwhile to consider.

6) Onshore wind power installation costs are greatly affected by grid connection and usage rules. Until now, power producers had to bear specific costs such as upper grid enhancement costs and in certain regions, storage battery installation costs due to regualations layed by the general electric utilities. These costs became a significant burden on the wind power producers. As of 2022, these rules that have caused individual power producers to excessively bear costs related to infrastructure development and grid stabilization, are being banned, and consequently, a decline in installation costs are already observed and expected to continue in the future.

7) Differences in contract type had an impact on several cost categories to a greater or lesser degree. The study showed that wind turbine costs could be reduced through direct procurement (contract type referred to as “other than EPC”) and transmission infrastructure costs could be reduced by separate engagement.

The above findings reported here is expected to serve as a basis for examining future costs in wind power generation.

In this study, a clear upward trend in wind turbine size was observed, and its impact on costs was empirically demonstrated. These findings highlight the following:

When making projections for 2030 generation costs, it is necessary to foresee the effects of technology advancements and evaluate the impact it will have on wind turbine costs and capacity factors. Taking such considerations into account will help minimize uncertainties when forecasting future gereration costs.

Secondly, the government's Power Generation Cost Verification Working Group (2021) assumes that only wind turbine costs will converge with international prices and that other costs will remain unchanged. This assumption is rather too simplified and the perspective that cost efficiency, which is expected to improve on the whole, will also contribute in cost reductions, is missing. In fact, the present study demonstrated that there were differences in costs depending on basic design contractor and contract types. It is possible to assume that cost efficiency will accelerate as domestic power producers become more skilled.

On the other hand, there were several issues that requires further investigation. While it was confirmed once again that major costs, such as wind turbine costs, are considerably higher in Japan compared to the rest of the world, the study was not able to identfy why there was an approximately 50,000 yen per kilowatt difference in turbine costs between Japan and other countries. Another result that ran counter to conventional wisdoms was that the cost per turbine turned out to be higher in lowland areas than in the mountainous areas. Further research will be needed to find out the factors lying behind this.

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Cost and Technology Trends for Onshore Wind Power in Japan

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