

自然エネルギー財団  
RENEWABLE ENERGY INSTITUTE

# Analysis of Wind Power Costs in Japan

January 2018



## 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.

[www.renewable-ei.org/en/](http://www.renewable-ei.org/en/)

## Author

Keiji Kimura, Senior Researcher at Renewable Energy Institute

## Acknowledgments

Renewable Energy Institute thanks all the wind power developers, equipment makers, consulting firms, companies, wind power researchers and experts who provided critical information and shared insightful comments this report greatly benefited from.

Among them, Renewable Energy Institute greatly thanks Japan Wind Power Association (JWPA), for offering valuable recommendations about the development of the research and assessment of the findings, as well as continuous and deep support for the entire project, especially with regard to collection of cost data.

This research was partially funded by JSPS KAKENHI Grant Number JP16H01800.

## Citation

Renewable Energy Institute, *Analysis of Wind Power Costs in Japan* (Tokyo: REI, 2018), 50 pp. – Translated from Japanese

© 2018 Renewable Energy Institute. All rights reserved.

Cover Photo Pattern Energy

## Table of Contents

Summary .....	1
Introduction .....	2
Structure of wind power costs .....	2
Classification of factors impacting the wind power costs .....	3
1. Wind power costs across the world .....	6
2. Relevance of data collected.....	10
Data collected .....	10
Relevance of cost data .....	10
Trends in the locational distribution .....	11
Trends in the size of wind power plants .....	13
Geographic trends of locations .....	13
3. Analysis of investment costs .....	15
Changes in investment costs over time.....	15
Relationship between the size of power plants and investment costs .....	16
Influence of different contract types on costs.....	17
Investment costs in Japan: International comparison .....	19
4. Analysis of wind turbine costs .....	21
Changes in turbine costs over time.....	21
Characteristics of turbines adopted in Japan .....	21
Factors that cause changes in turbine costs in Japan .....	22
5. Analysis of civil engineering and electrical work costs.....	26
Changes of costs over time.....	26
Analysis of cost factor increases .....	27
6. Analysis of operation and maintenance costs .....	35
O&M costs and their breakdown.....	35
International comparison of O&M costs .....	35
Factors that impact O&M costs .....	36
7. Analysis of the actual amount of electricity generated .....	40
Availability factor .....	40
Maintenance service providers and the actual availability factor.....	41
Capacity factor.....	41
Conclusions and themes for further research .....	43
Review of the current state of wind power costs in Japan.....	43
Study on possible cost reductions for wind power .....	44
Themes for further research.....	47
References .....	48

# Lists of Figures

- Figure 1 LCOE by power technology in Western Europe (2nd half of 2016)..... 6
- Figure 2 LCOE by power technology in the United States (2nd half of 2016)..... 6
- Figure 3 The United States: Average output per turbine, rotor diameter, and hub height ..... 7
- Figure 4 Europe: Average output per turbine, rotor diameter, and hub height ..... 7
- Figure 5 United States: Weighted-average capacity factor by commercial operation year (2015) ..... 8
- Figure 6 Market price of wind turbines (US and global) ..... 9
- Figure 7 Locational distribution among wind power plants in Japan..... 12
- Figure 8 Locational distribution among power plants in the sample data..... 12
- Figure 9 Breakdown of wind power plants by size ..... 13
- Figure 10 Breakdown of wind power plant locations by geography..... 14
- Figure 11 Changes of investment costs (median) by item..... 16
- Figure 12 Investment costs of power plants and their size..... 17
- Figure 13 Distribution of contract types (power plant basis) ..... 18
- Figure 14 Costs for related items between different contract types ..... 19
- Figure 15 Investment costs for wind power: ..... 20
- Figure 16 Changes of turbine costs (median & average) ..... 21
- Figure 17 Average hub height and rotor diameter in the sample data ..... 22
- Figure 18 International comparisons of turbine costs and prices ..... 23
- Figure 19 Changes of turbine costs, steel prices, and exchange rates ..... 23
- Figure 20 Relation between the size of power plants and turbine prices ..... 25
- Figure 21 Changes of civil engineering costs (median & average)..... 26
- Figure 22 Changes of electrical work and connection costs (median & average)..... 26
- Figure 23 Civil engineering costs by type of geographic feature..... 27
- Figure 24 Changes in locational conditions by period ..... 28
- Figure 25 Correlation between electrical work and connection costs and the distance from a grid connection point ..... 28
- Figure 26 Average distance to a grid connection point ..... 29
- Figure 27 Relationship between civil engineering costs and the size of plants (left)..... 29
- Figure 28 Relationship between electrical work costs and the size of plants (right) ..... 29
- Figure 29 Construction costs deflator ..... 30
- Figure 30 Changes of hourly wages among constructors (with 5 employees or more) (2010 = 100) 31
- Figure 31 Price indexes of construction materials (plain steel & liquid concrete) for cities..... 31
- Figure 32 Changes of copper prices in Japan (annual average) ..... 32
- Figure 33 Relationship between construction periods and civil engineering costs: ..... 33
- Figure 34 Construction period for wind power plants equipped with a single turbine ..... 34

Figure 35 O&M costs (median).....	35
Figure 36 Comparison between Germany and Japan in O&M costs .....	36
Figure 37 Capacities installed on an annual basis (2005–2016) and.....	37
Figure 38 Size of power plants and regular maintenance & administration costs.....	37
Figure 39 Share of O&M service providers .....	38
Figure 40 Regular maintenance & administration and repair costs.....	39
Figure 41 System availability factor .....	40
Figure 42 Actual availability factors by type of O&M service providers .....	41
Figure 43 Average capacity factor by region.....	42
Figure 44 Capacity factor (average & median) .....	42

## List of Tables

Table 1 Breakdown of investment costs (before tax) .....	3
Table 2 Breakdown of O&M costs (before tax) .....	3
Table 3 Changes in regulatory and institutional frameworks .....	4
Table 4 Overview of the data collected .....	10
Table 5 Comparison of cost data .....	11
Table 6 Changes in investment costs (3-year interval) .....	15
Table 7 possible factors for cost rise .....	27
Table 8 Timetable for construction of a single turbine with a capacity of 1.5 MW (Ex.) .....	33
Table 9 Influences on wind power costs in recent years .....	43

## Summary

Wind power is to be one of the cornerstones to build upon a sustainable energy system in Japan. A critical issue to achieve this goal is, however, the high cost of wind power in the country. Cost reduction of wind power in Japan therefore needs to be urgently addressed. To this end, Renewable Energy Institute has led a detailed analysis of the cost structure of wind power in Japan, based on actual cost data provided by power producers, which key findings are summarized below:

### (1) Investment costs

Turbine costs have decreased in recent years. After the revision of the Building Standards Act in 2007, which notably introduced tighter earthquake-resistance regulations, developers in Japan had to pay prices significantly higher than global prices when concluding a procurement contract for wind turbines (around 2008). However, they recently began to benefit from falling global turbine costs. That seems to reflect greater attractiveness of the Japanese market after introduction of a feed-in tariff (FiT) scheme in July 2012.

Meanwhile, the construction work-related costs (e.g. civil engineering and electrical work costs), are showing rapid increase due to factors that are not always possible to identify. In some parts of the Tohoku region (Northeast Japan), local factors, such as the soaring labor costs and material prices for civil engineering due to the reconstruction demand after the Great East Japan Earthquake, might be a factor for the rising costs. However, that hardly explains why wind power projects alone are experiencing rapid increases in construction work-related costs, while the nationwide construction cost deflator rose by only a few percentage points. In this regard, some experts and business operators stated that the lack of developers' expertise and financing capability might be among the factors for the cost increase. In addition, construction lead time is observed to be getting longer, although the clear causes for that have not been identified.

### (2) Operation and maintenance costs

Regular maintenance & administration costs account for the largest part of the operation and maintenance (O&M) costs. Facilities that came into operation after the introduction of the FiT saw their regular maintenance & administration costs double from their prior level. In this respect, some experts and maintenance service providers stated that with the support of the FiT, developers can now spend more for operation management. Regular maintenance & administration costs have also turned out to be negatively correlated with the annual installed capacity. Some experts stated that maintenance is more difficult for turbine models installed in small numbers, which may have something to do with the inverse relationship.

### (3) Actual amount of electricity generated

Among the facilities that came into operation after the introduction of the FiT, capacity factors have increased in average. Behind this improvement lie two possible factors. One is the locational factor; since the introduction of the FiT, more facilities have been constructed in Northern Japan, a region with better wind resources. Before the introduction of the FiT, wind power installed capacity was often restricted by quotas set by conventional electricity utilities. With the FiT, developers are allowed to file an application for grid connection anywhere without any quota allotted by electricity utilities. That seems to have helped construct power plants in locations with better wind conditions. The second factor is the industrial. Since the introduction of the FiT, capacity factors have also been rising at facilities located in other areas than Northern Japan. That might be attributable to some sampling bias, or it may reflect a higher efficiency achieved by the combination of better availability factors, as well as higher hub height, and larger swept area.

## Introduction

Wind power should be a cornerstone of a sustainable energy system in Japan. Taking into account technical, economical and legal constraints, onshore wind power potential is estimated to be significant; 280 gigawatts (GW).<sup>1</sup> And across the world, the levelized cost of electricity (LCOE) of onshore wind power is falling to the lowest among all power technologies demonstrating its strong economic competitiveness.

In Japan, however, the cost of wind power generation is higher than observed globally (Chapter 1). Furthermore, data from the Agency for Natural Resources and Energy (ANRE) of Japan show that investment and operation & maintenance (O&M) costs have been rising since the introduction of a feed-in tariff (FiT) scheme in July 2012. Improving the economic efficiency of wind power generation is a significant challenge to be addressed now. Hence to support the massive and economically sustainable deployment of wind power in Japan, studies on its future economic viability need to be conducted.

To this end, this report analyzes actual cost data offered by wind power developers to clarify the current cost structure of wind power in Japan and identify key factors affecting such cost structure. It also aims to advance suggestions on how to reduce wind power costs in Japan.

To reach this goal, data provided by the member companies of Japan Wind Power Association (JWPA), with the cooperation of JWPA itself, have been analyzed. The data collected cover wind power plants with a total capacity of 1 MW or more that came into operation from 2005 onwards. The quantitative analyses were supplemented by interviews with wind power equipment producers, technical consulting firms, maintenance service providers, relevant experts and researchers, and financial institutions to better interpret the data.

For comparison, this research has also examined wind power costs across the world. Information was gathered through a range of relevant publications and extensive interviews of researchers, business people, and companies related to wind power in Europe.

### Structure of wind power costs

The LCOE for wind power is defined as normalized costs for 1 kWh of electricity produced by power plants throughout their life cycle. The LCOE is determined generally by four elements:

(1) Investment costs. They include costs for constructing wind power plants, connecting them to the grid, and disposing of them when decommissioned. This research examines costs for construction and grid connection. Table 1 shows the breakdown of investment costs.

---

<sup>1</sup> See the Ministry of the Environment (2016). It refers to potential capacities of areas where the wind blows at an annual average velocity of 5.5 m/s at the height of 80 m which satisfy certain national and social conditions. The social conditions include, among others, the area being located at an appropriate distance from residential districts, and being out of regulated areas where no development is permitted.

**Table 1 Breakdown of investment costs (before tax)**

Item	Description
Turbine costs	Costs for procuring wind turbines
Transportation & installation costs	Costs for transporting turbines and other components (by sea & land), storing them, and erecting and installing wind turbines
Civil engineering costs	Costs for preparing sites and laying foundations, modifying facilities at landing ports, and constructing and widening roads for transportation
Electrical work costs	Work for wiring and piping on the premises, etc.
Grid connection cost	Costs for installing power wires, breakers, and meters, construction work contributions paid to transmission and distribution system operators, etc.
Planning & development costs	Costs for work to be done before construction work starts, including wind resource quality survey and acquisition of land, but excluding costs for environmental impact assessment
Environmental impact assessment costs	Costs for environmental impact assessment
Others	Costs not mentioned above

Source: Renewable Energy Institute

(2) Operation and maintenance (O&M) costs. They include costs for operating power plants, which include land rent, insurance premium, and repair costs, among others. O&M costs represent an annual total of these costs. This report classifies the costs into the items listed below.

**Table 2 Breakdown of O&M costs (before tax)**

Item	Description
Regular maintenance & administration costs	Day-to-day costs for personnel working for O&M, measurement of data, and regular inspections, etc. This figure excludes insurance premium, tax, and land rent.
Insurance premium	Annual average premiums for fire, lightning, and other property insurance, liability insurance, and profit insurance
Land rent	Any money paid to rent land used for power plants, etc.
Repair costs	Costs for repairing damaged facilities, equipment, etc.
Others	Costs not mentioned above

Source: Renewable Energy Institute

(3) The annual amount of electricity generated. Between two power facilities operating with the same total cost, the LCOE is lower for one with more annual amount of generation. The annual amount of generation at a power facility is determined by its installed capacity and capacity factor.

(4) The internal rate of return (IRR). Any capital, owned or borrowed, can be raised for a project only when investors can expect a certain level of profit. Profitability of a project is represented by its IRR. A project with higher risk would fail to raise capital when it is unlikely to achieve a higher IRR. In other words, the IRR represents the cost for raising capital. An IRR required for ordinary wind power projects depends on a variety of factors, such as current conditions of the financial market, and risks the projects are exposed to. Generally, it is determined by the interest rate of borrowings from financial institutions, and their shares in the total capital. This research refrains from dealing with the IRR, as information obtained from business operators on interest rates of borrowings and their shares was insufficient.

### Classification of factors impacting the wind power costs

Various factors impact the LCOE of wind power, and can be roughly classified into international and domestic factors. International factors include global trends of wind turbine technologies, the supply and demand balance in the market, volatility of prices of materials for turbines, and currency exchange rates, all of which affect prices of wind turbines produced overseas. Japanese turbine manufacturers are also affected by material prices in the global market and exchange rates, as they cannot procure and produce everything in the country.

Domestic factors are classified roughly into three categories—locational, institutional, and industrial. Among the locational factors, the most significant are natural conditions, such as geography, geology, and wind resource quality. The wind resource quality affects the strength design of turbines, as well as the amount of electricity generated. The geography and geology may affect costs of civil engineering work required.

Institutional factors refer to regulatory and institutional frameworks that affect construction and operation of wind power plants and their costs. They include a broad range of frameworks set by national and local governments, as well as transmission and distribution system operators (still belonging to the so-called “former general electric utilities,” the 10 vertically integrated utilities). Major changes in related frameworks set by the national government can be found in Table 3 below. These frameworks have great impacts on wind power costs. For instance, the tightening of regulations may directly or indirectly drive up costs, and hinder growth of the market by making fewer areas available for power plant constructions.

**Table 3 Changes in regulatory and institutional frameworks  
set by the national government for wind power**

Fiscal year	Major changes to policies and regulations	Outlines
2003	Enforcement of the Act on Special Measures Concerning New Energy Use by operators of electric utilities (RPS Act)	Electricity utilities were obliged to purchase a fixed amount of electricity generated by new energy sources on an annual basis. Its impact on growth of renewable energy was limited, as the obligatory purchase was small.
2007	Revisions to the Building Standards Act	The revised Act required turbines over 60 m to satisfy earthquake-resistance standards comparable to those for skyscrapers.
2009	Clarification of interpretations of the Ordinance for Enforcement of the Agricultural Land Act	Exceptions from the land use restrictions for Highly Productive Agricultural Land became inapplicable to wind power projects. As a result, Highly Productive Agricultural Land became practically unavailable for constructions of power plants.
2010	Termination of the Support Program for New Energy Operators, etc.	The Program, granting subsidies to commercial wind power operators in the private sector for part of their investment costs, was terminated.
2012	Enforcement of the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities (FiT Act)	Electricity utilities were obliged to enable renewable energy producers to get connected to the grid, and conclude contracts with them under statutory terms and conditions. The institutionalized contract conditions and obligations imposed on the utilities significantly helped wind power producers to improve business conditions.
2012	Revisions to a Cabinet Order for adding wind power plants to the list of activities subject to environmental impact assessment	Wind power plants with a capacity of 10 MW or more came to be subject to the Environmental Impact Assessment Act, making certain statutory procedures obligatory.
2014	Enforcement of the Act on the Promotion of Renewable Energy Electric Power Generation Harmonized with Sound Development of Agriculture, Forestry and Fisheries (Rural Communities Renewable Energy Act)	The Act enabled a type of Highly Productive Agricultural Land, Class-1, to have its land use changed under specific conditions.

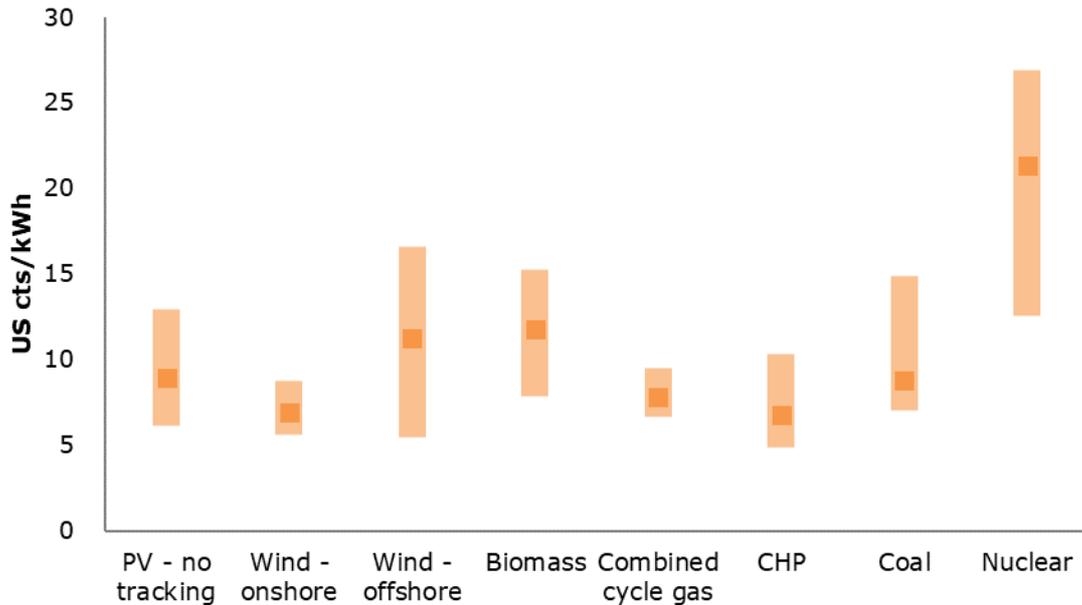
Source: Renewable Energy Institute

Finally, industrial factors are those derived from conditions of wind power business and technologies and related sectors. For example, larger-scale power plants can produce electricity at a lower cost per kW. Costs may also depend on the size of developers, rather than the size of individual power plants. Larger developers have richer business experience and greater procurement capabilities that may allow them to reduce costs for development. In addition, labor costs and prices of related materials procured in Japan would also affect the wind power costs. As the market grows larger, the economies of scale, for instance, may be more significant, with related materials and services supplied at lower prices.

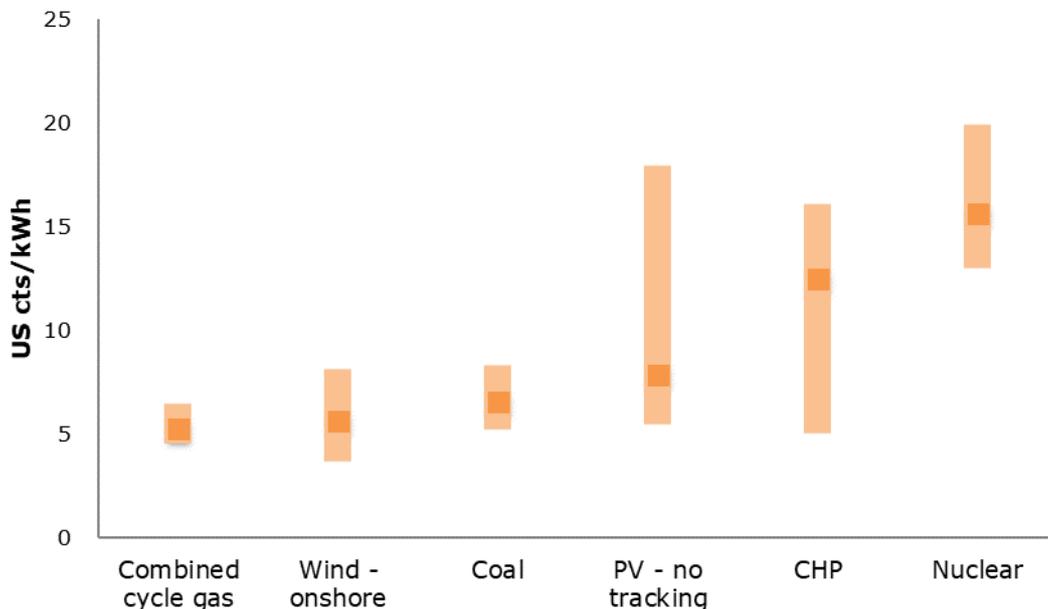
Some of these factors can be regarded as independent while others may be correlated. For instance, the international factors and the domestic locational factors can be considered independent. On the other hand, the size of markets, which is one of the domestic industrial factors, is largely affected by domestic locational and institutional factors. Representing and analyzing all these factors in a consistent and uniform manner is quite a difficult challenge.

# 1. Wind power costs across the world

New wind power has been considered more cost competitive than any other power technology in the world. For instance, comparison of LCOE between power plants newly constructed in the second half of 2016 shows that average costs of onshore wind is 5.6 US cents/kWh in the United States and 6.9 US cents/kWh in Western Europe. That is at least as competitive as conventional power sources such as fossil and nuclear power (Figure 1 & 2).



**Figure 1 LCOE by power technology in Western Europe (2nd half of 2016)**  
 Source: Adapted from Bloomberg New Energy Finance (2016) "H2 2016 EMEA LCOE Outlook"

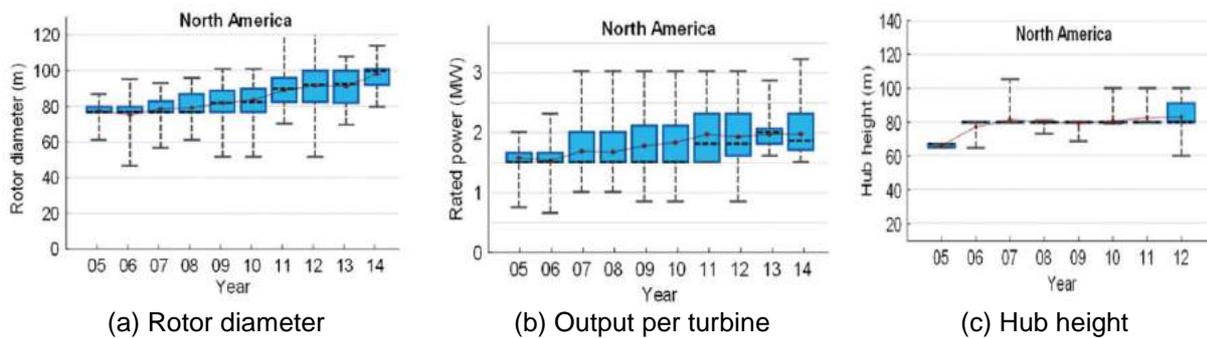


**Figure 2 LCOE by power technology in the United States (2nd half of 2016)**  
 Source: Adapted from Bloomberg New Energy Finance (2016) "H2 2016 AMER LCOE Outlook"

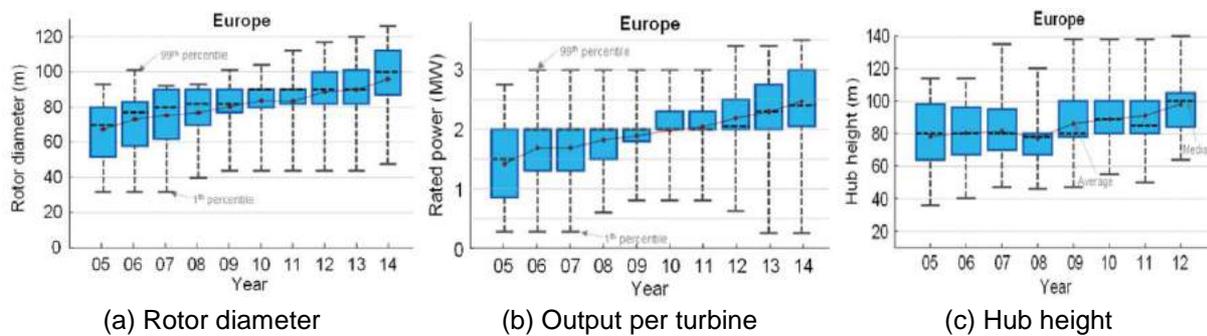
Cost competitiveness of wind power has improved globally thanks to several factors:

The adoption of advanced wind power technologies have helped achieve a greater performance ratio (IEA Wind Task 26, 2015; IRENA, 2015; Wisner and Bolinger, 2016). The recent trend in the United States is that individual turbines are equipped with longer blades and larger rotor diameter, with little change in the hub height, and more output (Figure 3). A larger rotor diameter offers a turbine a larger swept area. That enables a single turbine to catch more wind, even at a lower speed and generate more electricity. Advanced technologies have allowed rotors to have a larger diameter while controlling increases in their weight.

In Europe, in addition to enlarging rotor diameters, towers have been improved to hold hubs higher (Figure 4). Wind turbines with a higher hub height can catch stronger winds. These technological improvements enable wind farms at lower wind speed sites to generate comparable amount of electricity as sites of stronger wind.



**Figure 3 The United States: Average output per turbine, rotor diameter, and hub height by commercial operation year**  
Source: Gonzalez and Arantegui (2016)

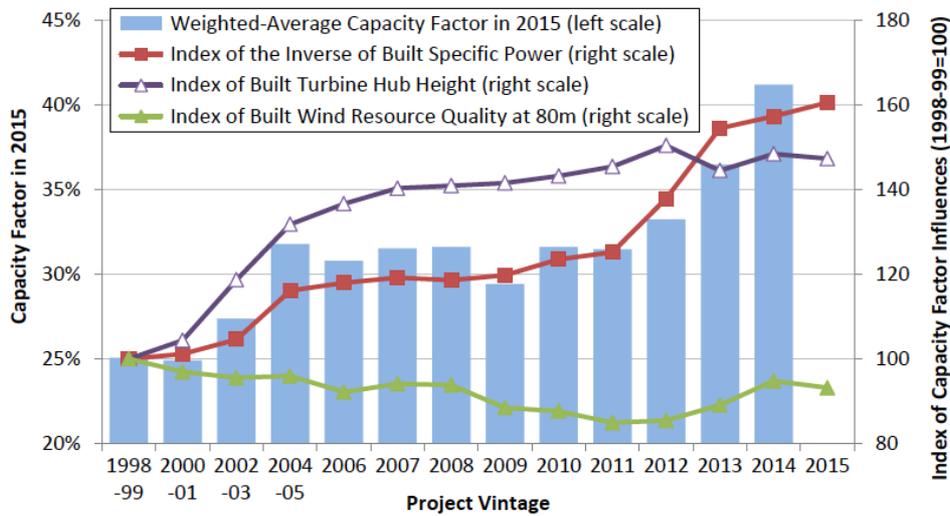


**Figure 4 Europe: Average output per turbine, rotor diameter, and hub height**  
Source: Gonzalez and Arantegui (2016)

These advanced technologies also allow wind power plants with poorer wind resource quality to operate at higher capacity factors. Figure 5 shows the capacity factor in the United States and impacts of several directly related factors—wind resource quality, hub height, and specific power (rated output per swept area).<sup>2</sup> The capacity factors have greatly improved among wind farms built in 2012 and after. The wind resource quality (green line) hit the bottom in 2011 and 2012, then picked up moderately, but without significant improvement. The resource quality at locations for farms built in 2013 and 2014 is almost the same as that for those built in 2010, and 2007 and 2008, respectively. The hub height (purple line) has virtually been leveling off. It is the specific power (red line) that has achieved a great improvement since 2012. The growth of the specific power index implies that the size

<sup>2</sup> The specific power of a wind turbine represents its rated power divided by its swept area. The swept area is calculated using its rotor diameter.

of the swept area grew faster than the output, consequently contributing to the improvement in capacity factor since 2012.



**Figure 5 United States: Weighted-average capacity factor by commercial operation year (2015)**

Source: Wisser and Bolinger (2016)

Note: The light-blue line indicates weighted-average capacity factors in 2015. The green line shows indices of the wind resource quality at 80 meters for turbines built in each year. The purple and red lines represent indices of the hub height and the inverse of specific power, respectively. A turbine with the same rated output and a larger swept area achieves a lower specific power. As the value gets lower, the capacity factor goes higher.

Another notable factor is that wind turbine prices have significantly declined. Since 2008, the market price per kW has been constantly falling (Figure 6). Until that year, between 2002 and 2008, the turbine price had been rapidly increasing. Bolinger and Wisser (2011) attributed the increases to seven factors, and analyzed them in detail to identify the influences of each.

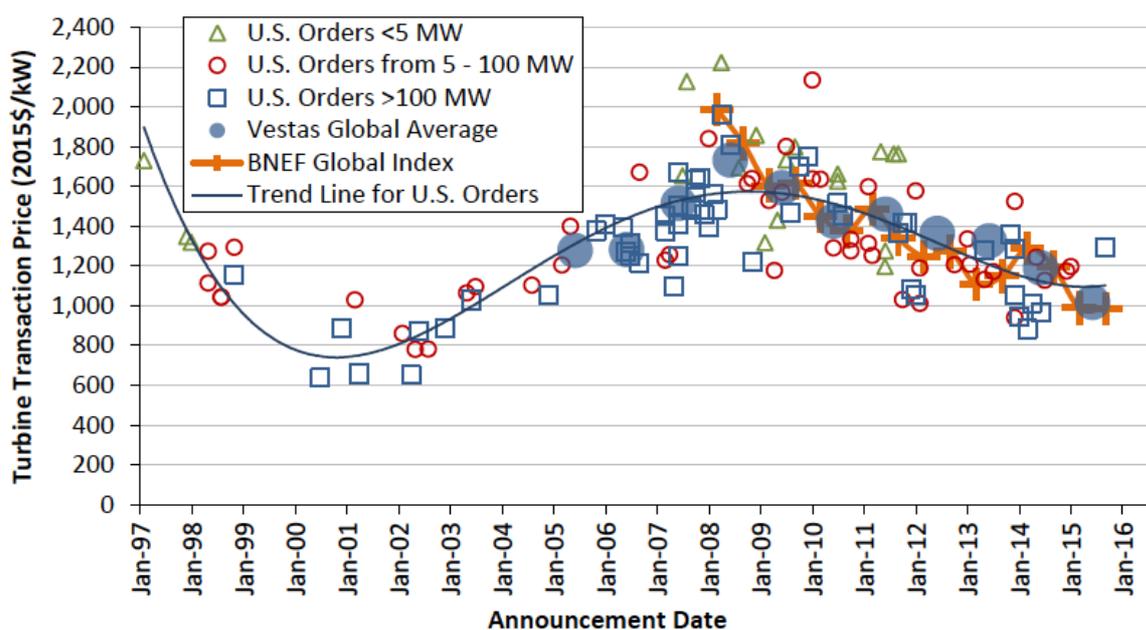
Their analysis revealed that the greatest contribution had come from the enlargement of turbines in size, such as higher hub height and larger rotor diameter. However, the consequent price increases do not necessarily serve disadvantageously because, as mentioned before, a larger turbine is capable of producing more electricity.

The second largest contributor is the currency exchange rate. During the period, despite its growing share of domestically manufactured products, the United States imported some 60% of wind turbines and components. Their prices are influenced by exchange rates with currencies of major exporters. The analysis of Bolinger and Wisser showed import prices had been influenced mainly by the euro, Danish krone, and Japanese yen. During this period, the US dollar fell significantly against these foreign currencies, which resulted in increases in wind turbine prices on a US dollar basis.

The third contributor lied in the increased labor cost. In general, a greater deployment of wind power leads to higher efficiency and/or a larger economies of scale, driving down the labor cost per kW. However, an important rapid increase of demand may push up labor cost. Also, the turbine manufacturers required higher profit margins in the sellers' market since 2005.

Their analysis also presented price rises of materials, such as steel, as another factor leading to cost increases.

Turbine prices have been driven up by these factors until 2008. They have been decreasing since then, notably because of growing competition between manufacturers resulting in cost reduction (Wisser and Bolinger, 2016, p. 52). Bloomberg New Energy Finance (BNEF) (2017) reports that in the second half of 2016, turbines were sold at around 1,120 USD per kW, 40% cheaper than in the first half of 2009.



**Figure 6 Market price of wind turbines (US and global)**

Source: Wisser and Bolinger (2016)

Improvement of turbines technical performances around the globe resulted in turbine price decline and lower LCOE of wind power. According to BNEF's global benchmark, the average LCOE of onshore wind<sup>3</sup> was 9.4 US cent/kWh in 2010 and fell to 7.4 US cent/kWh in 2016 (both on a 2015 US basis).

Meanwhile, BNEF estimates the average LCOE of onshore wind in Japan at 16.5 US cents/kWh (on a 2015 USD basis) in 2016, one of the highest in the world (BNEF, 2016d). Similar results have been given by other surveys conducted in Japan. According to the Power Generation Cost Verification Working Group, which performed an analysis in 2015, wind was assessed as a less economical energy source in 2014 than nuclear, thermal, and hydro power, even with social costs of CO<sub>2</sub> emissions taken into account, with a prediction that it would remain so in 2030. This makes wind power an unattractive resource to be harnessed and a low priority in Japan's energy policy.

International comparisons demonstrate that onshore wind power costs in Japan are too high. It is therefore necessary to identify the factors that keep the costs of wind power so high. Without this effort, onshore wind power will not find its place in Japan's environmental and energy policies.

<sup>3</sup> BNEF (2016a) sets a benchmark for the cost of power generation every quarter or six months. The number here is the average of each quarter, considered to be an annual average. Despite BNEF (2016a)'s benchmark being based on nominal value, the value of money changes year by year owing to inflation or other reasons. As a result, the yearly changes in money value are considered when each year's benchmark is compared. The number here is based on the value of the US dollar in 2015.

## 2. Relevance of data collected

### Data collected

For this research, with the support of JWPA, the author distributed questionnaires among wind power developers during the autumn of 2016 to collect cost data. In March 2017, we had obtained information on 38 wind power plants that started commercial operation after 2005 (Table 4). These included 215 wind turbines, for a total installed capacity of 370 MW. According to the New Energy and Industrial Technology Development Organization (NEDO) of Japan's data (2016), 211 wind power plants (1 MW or more) have started operation in Japan since 2005 (1,290 turbines, with a total combined installed capacity of 2,290 MW). In the population of the country's wind farms that started operation after 2005, the response rate would be 18%.

Among the data of the sample, the average output per turbine stands at 1.8 MW, approximately the same as that in the population. In terms of size, the average output per turbine in the population was 11 MW, slightly larger than the average among the data of the sample; 10 MW among the data of the sample. Especially, the turbines that started commercial operation in 2008-2010 or 2014-2016 are smaller in size than the average in the population. For the analyses performed below, it must be noted that the data collected for 2008-2010 and 2014-2016 come from power plants that are smaller than the average power plants of the population.

**Table 4 Overview of the data collected**

Commercial operation year (Calendar year)	2005–07	2008–10	2011–13	2014–16	Total
No. of power plants	15 (87)	9 (49)	8 (36)	6 (39)	38 (211)
Total installed capacity (MW)	151 (741)	117 (755)	73 (354)	30 (441)	370 (2,290)
No. of turbines	108 (470)	57 (402)	35 (171)	15 (208)	215 (1,290)
Average turbine output (MW)	1.4 (1.5)	2.0 (1.9)	2.1 (2.0)	2.0 (2.1)	1.7 (1.8)
Average plant size (MW)	10 (9)	13 (16)	9 (10)	5 (11)	10 (11)

Source: Adapted from Renewable Energy Institute and NEDO (2016)

Note: Figures between brackets represent totals in Japan. The table excludes data of power plants that have not come into operation.

### Relevance of cost data

Any large deviation between cost data collected for this research and those released by the ANRE (regarded virtually as data of the population) suggests that the former might be biased. To verify the relevance of the cost data of the sample, they were compared with the cost data released by the ANRE on power plants that fall under similar categories. For investment costs, the comparison gave no significant deviation in the average and median. For O&M costs, however, the data released by ANRE includes those on the facilities that came into operation before 2005, while data collected for this research only cover the plants coming into operation in 2005 or later. This coverage difference leaves it difficult to check the relevance of cost data collected.

The data of the sample show little deviation from the population data in terms of average and median although some large dispersion is found among the data themselves. As the dispersion in the population is unknown in the first place, the relevance cannot be examined. The large dispersion and the limited number of the sample may result in a large error in the findings. This point should be taken into account.

**Table 5 Comparison of cost data**

		ANRE	Data collected
Investment costs (Commercial operation after FiT)	Average (million JPY/MW)	342	337
	Median (million JPY/MW)	312	316
	Standard deviation (million JPY/MW)	n.a.	85
	Sample size (after FiT)	49	10
O&M costs (Approved facilities)	Average (million JPY/MW/y)	15.2	11.7
	Median (million JPY/MW/y)	11.3	11.0
	Standard deviation (million JPY/MW)	n.a.	6.7
	Sample size (Approved facilities)	281	33

Source: Adapted from ANRE (2016)

**Trends in the locational distribution**

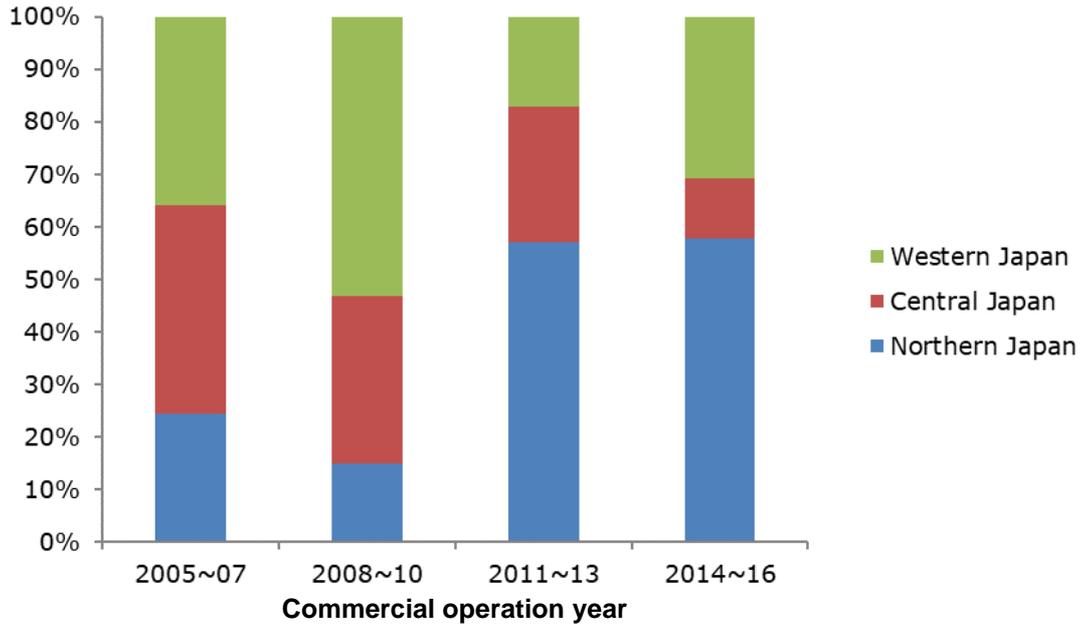
The location of a wind power plant has a significant importance on its economic profitability. Some places may offer excellent wind resource quality, while others may not. In general, Hokkaido and Tohoku regions are considered very suitable for building wind power plants, because of the high quality of their wind resources. To avert the risk of identifying individual power plants, this research divides the land of Japan roughly into three areas to examine the trends in the distribution of wind farms. Hokkaido and Tohoku regions are grouped into Northern Japan, while the Kanto (Tokyo area), Chubu, and Hokuriku regions constitute Central Japan. The Kansai region and the other western areas form Western Japan.

First, the locational distribution of wind farms across Japan can be analyzed based on data released by the NEDO (2016). Figure 7 shows changes in the locational distribution of power plants by commercial operation years. Most of the plants that started commercial operation between 2005 and 2010 are located in Western and Central Japan. Since the period of 2011-2013, the share of plants located in Northern Japan has increased. FiT in Japan started since July 2012.

With its excellent wind resource quality and great availability of land, Northern Japan naturally has higher potential for wind power. However, wind power development had been restrained there as the still vertically integrated incumbent electricity utilities have set upper limit capacity which wind power can interconnect because of limited down ramping capability, they claimed.<sup>4</sup> Generally, deployment progresses faster in more advantageous areas. The opposite occurred in Japan.

---

<sup>4</sup> For instance, Tohoku Electric Power Company set the grid connection capacity for 2004 and 2008 at 520 MW and 850 MW, respectively. The concept of grid connection capacity has already been disused. As of April 2017, the 30-day output threshold for Tohoku Electricity is set at 2.51 GW, but some grid capacity is available above the limit.

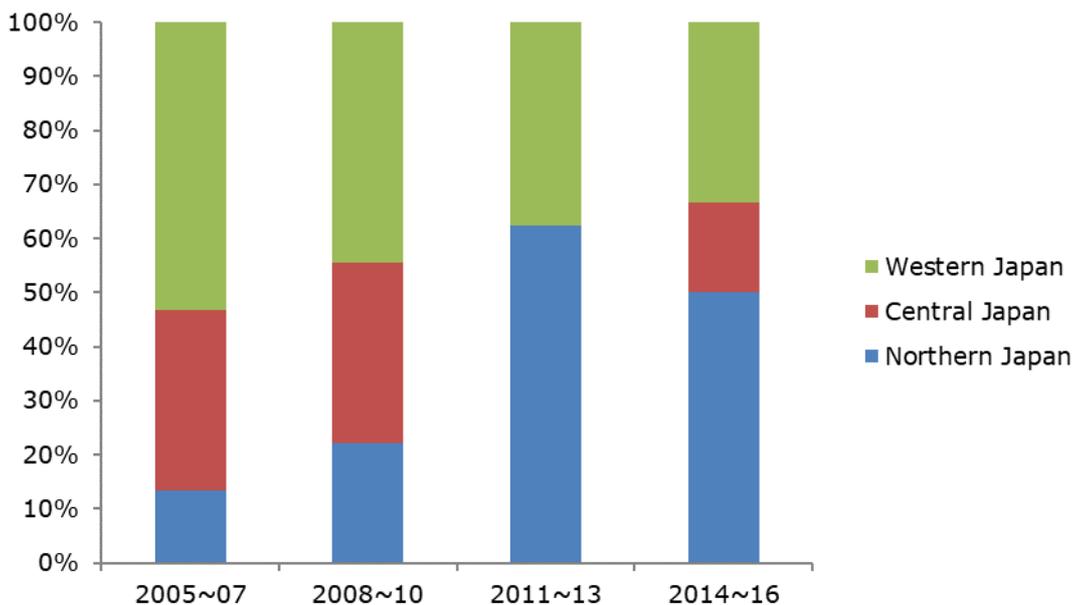


**Figure 7 Locational distribution among wind power plants in Japan**

Source: Adapted from NEDO (2016)

Note: For each period, the percentage of a region is calculated by setting its denominator as the number of power plants coming into operation all around Japan at the time with a capacity of 1 MW to produce electricity for sale, and its numerator as the number of those which started operating in the relevant region.

Then, the trends of the locational distribution in the collected sample data is shown below (Figure 8). Any large deviation between the trends observed here and the trend of the entire population would indicate that the sample is biased. Upon comparing Figures 7 and 8, large deviations are not observed in the locational distributions in any period, although the data on power plants located in Central Japan are unavailable for the period between 2011 and 2013.

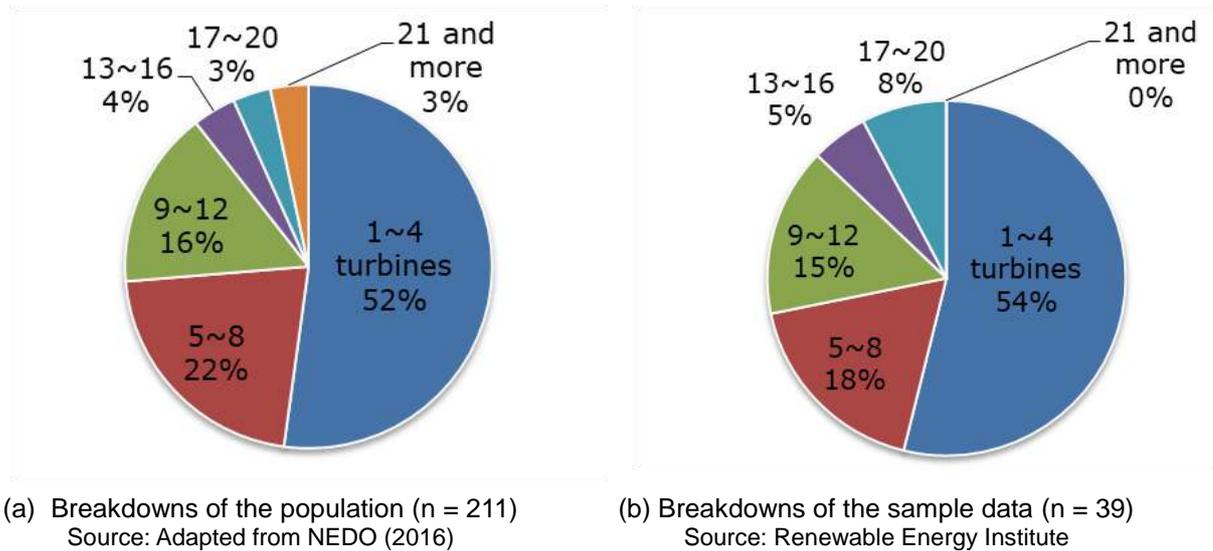


**Figure 8 Locational distribution among power plants in the sample data**

Note: For each period, the percentage of a region is calculated by setting its denominator as the number of power plants coming into operation all around Japan at the time with a capacity of 1 MW to produce electricity for sale, and its numerator as the number of those which started operating in the relevant region.

## Trends in the size of wind power plants

Different sizes of wind power plants may result in different profitability. Figure 9 shows the distribution of power plants coming into operation from 2005 onwards in Japan with a capacity of 1 MW by size. Slightly more than half (52%) of the plants are equipped with four turbines or fewer. The second largest group, those with five to eight turbines, accounts for 22%. The rest is a group of larger plants, with nine turbines or more. The collected sample data indicate similar tendencies, and no significant difference is observed.



**Figure 9 Breakdown of wind power plants by size**

## Geographic trends of locations

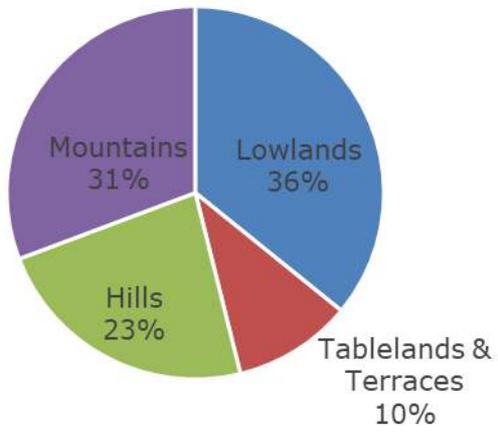
Upon constructing a wind power plant, its geography is one of the critical determinants. Japan has 60% of its land covered by mountains.<sup>5</sup> As stated in a study, a wind power plant constructed in a mountainous area may have to bear higher costs for transporting and installing wind turbines and building roads (Mizuno, 2013, p. 17). That means that geographical conditions of wind power plant locations may constitute an important factor for cost analysis. However, there are no available statistical data on the geography of wind power plant locations in Japan at the country level.<sup>6</sup> This analysis therefore used data offered by the power producers in the sample (Figure 10).

Analysis of the data reveals that 36% of the power plants are located in lowlands while 31% are found in mountains. Those constructed in hills account for 23%. That is, 54% of the plants have been constructed across the mountains and hills combined, or complicated terrains.

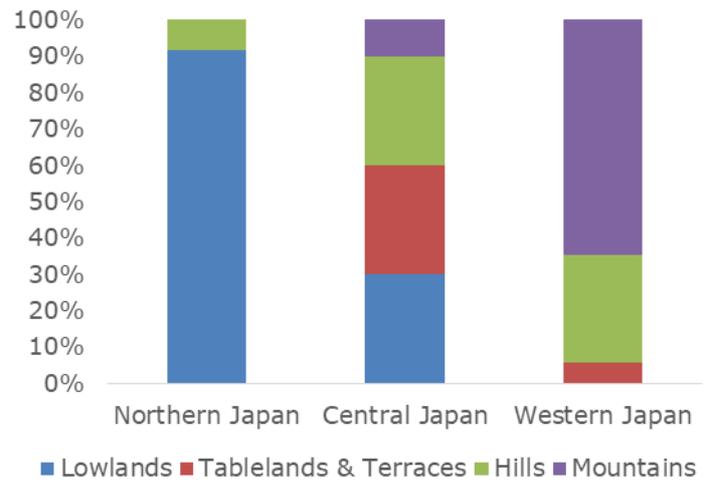
Comparison between the regions reveals significant differences. In Northern Japan, 90% of the wind power plants are located in lowlands. Central Japan sees 60% of the plants located in lowlands or tablelands. In contrast, more than 90% of the power plants are located in mountains and hills in Western Japan. These differences between the regions may reflect differences in their land use and wind resource quality.

<sup>5</sup> Calculated based on the Statistics Bureau of the Ministry of Internal Affairs and Communications, "Area by Configuration, Gradient and Prefecture."

<sup>6</sup> Strictly speaking, the "Location Information on Wind Power Generators," published by the East Japan Civil Aviation Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, contains heights of wind turbines at their top, which include blades, from the ground and sea level. The difference between them at a location indicates its elevation. However, the geographical categories of lowland and mountain are not defined solely by elevation. Any correlation between the geography of locations and their elevation would be hard to find.



(a) National (n = 39)



(b) Regional

**Figure 10 Breakdown of wind power plant locations by geography**

Source: Renewable Energy Institute

### 3. Analysis of investment costs

#### Changes in investment costs over time

Investment costs, aggregated from the sample data, are shown in Table 6. Between 2005 and 2007, investment costs amounted to 210 million JPY/MW (median), roughly the same as, or a little lower than, the same level among the wind power plants around the world.<sup>7</sup> In Japan, however, investment costs, both the median and average, have since then increased. It is believed that, as typically seen in solar PV, greater deployment enables advancement of technologies and expertise, which in turn pushes down costs. Japan has seen the opposite phenomenon in wind power.

**Table 6 Changes in investment costs (3-year interval)**

Commercial operation year	2005-07	2008-10	2011-13	2014-16
Median (million JPY/MW)	210	295	305	355
Average (million JPY/MW)	213	295	299	371
Standard deviation (million JPY/MW)	26	68	37	94
Sample size	14	8	6	6

Source: Renewable Energy Institute

Note: To compensate for the limited sample size, the period of 12 years is divided into 4 groups of 3 years for analysis.

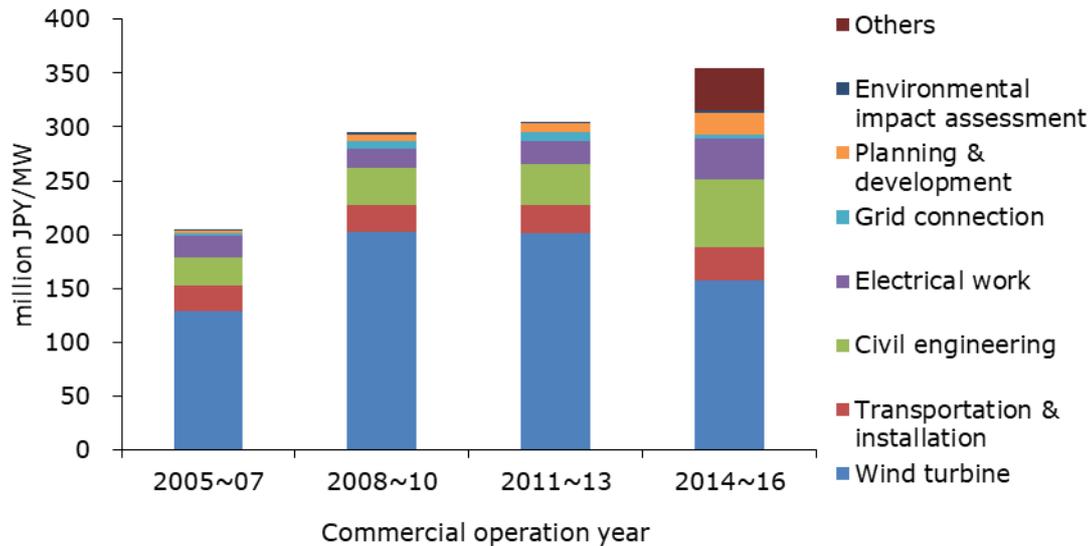
The first significant change occurred between 2008 and 2010, when investment costs increased sharply by 50% from approximately 200 million JPY/MW to almost 300 million JPY/MW. Little change had been seen until 2013. The second change in investment costs occurred between 2014 and 2016; the median increased by 50 million JPY/MW to 355 million JPY/MW. The data between 2014 and 2016 show a large divergence between the average and median, with a large standard deviation, indicating that they widely varied.

As shown before in Table 1, investment costs are composed of several items. Changes in investment costs by item can explain how much impact was caused by which item at what time (Figure 11). Between 2008 and 2010, investment costs increased by 50%, and the greatest contributor was an increase of wind turbine costs<sup>8</sup> (up 60 million JPY/MW in the median). Civil engineering and planning & development costs also rose (up 6 million JPY/MW and 4 million JPY/MW, respectively). Between 2014 and 2016, investment costs rose with sharp increases in various items, including civil engineering, electrical work, planning & development, and other costs. Other costs include those paid to engineering, procurement and construction (EPC) contractors,<sup>9</sup> and those paid by plant operators for, among others, construction-site management and related business, work-related accident compensation, erection insurance, and financing.

<sup>7</sup> According to IEA Wind (2006) and IEA Wind (2008), investment costs for wind power generation in Europe between 2006 and 2007 amounted to 1,000 to 2,000 EUR/kW, or 150,000 to 300,000 JPY (1 euro = 150 JPY).

<sup>8</sup> Here, "turbine costs" refers to costs for wind turbines that developers procure from manufacturers. Note that they are different from manufacturing costs for turbines.

<sup>9</sup> Business entities working under contract through the entire process of designing of, procurement for, and construction of plants.



**Figure 11 Changes of investment costs (median) by item**

Source: Renewable Energy Institute

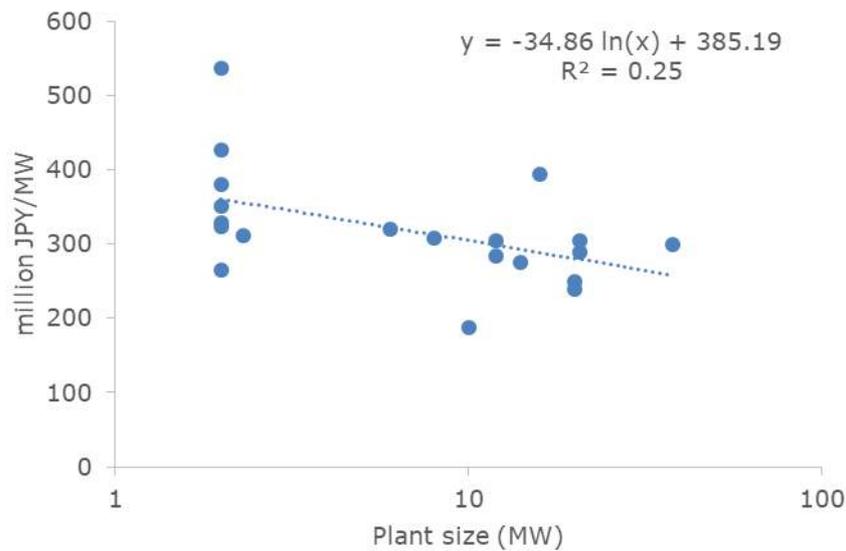
#### Relationship between the size of power plants and investment costs

The size of power plants is one of the industrial factors that may influence investment costs. Investment costs increased from the 2008-2010 period to the 2014-2016 period. However, any direct comparison must be done with caution, since, the average size of power plants changed between the two periods, as mentioned before. In this context, this section examines the relationship between investment costs and the size of power plants. Here, an analysis is performed for power plants that came into operation between 2008 and 2016 (Figure 12). Plants that started operating before 2008 are excluded because investment costs were extremely low in those years, a cause of bias that should be avoided.

It is found that for the relationship between investment costs and the size of plants, the logarithmic approximation model fits better than the linear approximation method, giving a coefficient of correlation (R) of 0.495, a medium level of correlation (N = 20, p-value = 0.026). This means, for instance, when the capacity of a plant increases from 5 MW to 10 MW, investment costs decrease fast while, from 10 MW to 15 MW, costs fall less sharply.

In practice, physical costs, such as material and labor costs, can only be reduced to a certain limit. Therefore, investment costs are unlikely to decline in a linear manner as the size of power plants grows. It would be rather natural to think that, among plants larger than a certain level, costs would decrease more slowly than the pace of their growth in size.

The analysis above would indicate that the average size of power plants coming into operation in the 2014-2016 period was about 5 MW, much smaller than the average size of 13 MW for those coming into operation in the 2008-2010 period, and therefore the investment costs were higher in the former period.



**Figure 12 Investment costs of power plants and their size  
(Commercial operation years between 2008 and 2016)**

Source: Renewable Energy Institute

### Influence of different contract types on costs

Level of expertise of the developers is one of the industrial factors that impacts costs of plants. One indicator of the level of expertise could be the number of wind power projects they have engaged in, suggesting experience level. However, any reasonable comparison is impossible for this research, because among those who offered data, there was no major developer who had been involved in 10 power plant projects or more. As an alternative, this section examines possible influences of different contract types adopted for projects on their costs.

Construction of a wind power plant includes a great variety of processes, including designing, procurement of turbines and other equipment, construction of roads, building of substations, transportation, site preparation, erection, and grid connection. Each of these processes can be contracted out to service providers. The abilities of the developers are reflected on their decisions about which processes to be outsourced and which to be done in-house.

Contracts for the processes related to the development of a wind farm can be classified into three major types:

- (1) EPC blanket contract (EPC): A contract with a single EPC contractor covering from designing and procurement all through construction.
- (2) Balance of plant (BOP): Developers procure wind turbines only, and outsource construction and other processes to a general contractor.
- (3) Separate engagement: Developers perform designing and procurement, and outsource each of the other processes, including construction, to different contractors, or perform some of them in-house.

According to some developers based in Europe "An advantage of the EPC type is that it allows us to concentrate on risk management. But with this approach, we have difficulty reviewing individual processes to see whether costs are reasonable. On the other hand, the separate engagement type helps us scrutinize a project in detail, leading possible contractors to compete between them at negotiations on pricing, and reduce costs." However, the separate engagement type can be adopted only by developers who themselves know enough about the processes to manage and supervise each of them appropriately, which requires considerable experience, knowledge, and expertise. For this reason,

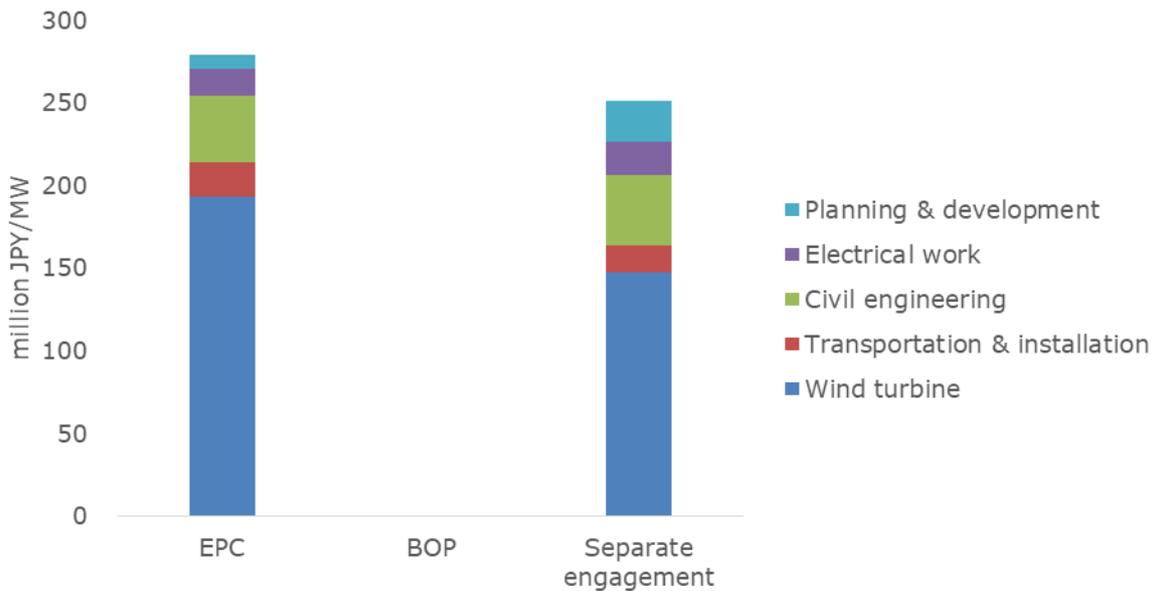
others stated, "For less experienced developers, the EPC type would be more favorable." These comments suggest that developers adopting the separate engagement approach are likely to have acquired a certain level of experience and/or expertise.

Below in this section, investment costs are compared between different contract types, with the focus placed specifically on some items that seem more sensitive to differences in contracting. First, Figure 13 shows the distribution of power plants between the three different contract types. EPC type contracts were concluded for 72% of them. Especially, 86% of the plants coming into operation between 2005 and 2010 adopted this approach. Meanwhile, with increases of the other two types of contracts between 2011 and 2016, the share of EPC fell to 50%, indicating a growing diversification between the contract types since 2011.



**Figure 13 Distribution of contract types (power plant basis)**  
 Source: Renewable Energy Institute

Next, for projects that came into operation in and after 2011, the year when a greater dispersion between the contract types became noticeable, the EPC and separate engagement types of contracts are compared in costs for planning & development, turbine procurement, and construction work. (The BOP type of contracts is omitted as the sample size is too small.) It is observable that turbine costs are lower in the separate engagement type than in the EPC approach, by an average of 31 million JPY/MW and a median of 46 million JPY/MW. Little difference is found in costs for construction, such as civil engineering and electrical work, between the two types. In contrast, planning & development costs are higher in the separate engagement type, by an average of 15 million JPY/MW and a median of 16 million JPY/kW.



**Figure 14 Costs for related items between different contract types**

Source: Renewable Energy Institute

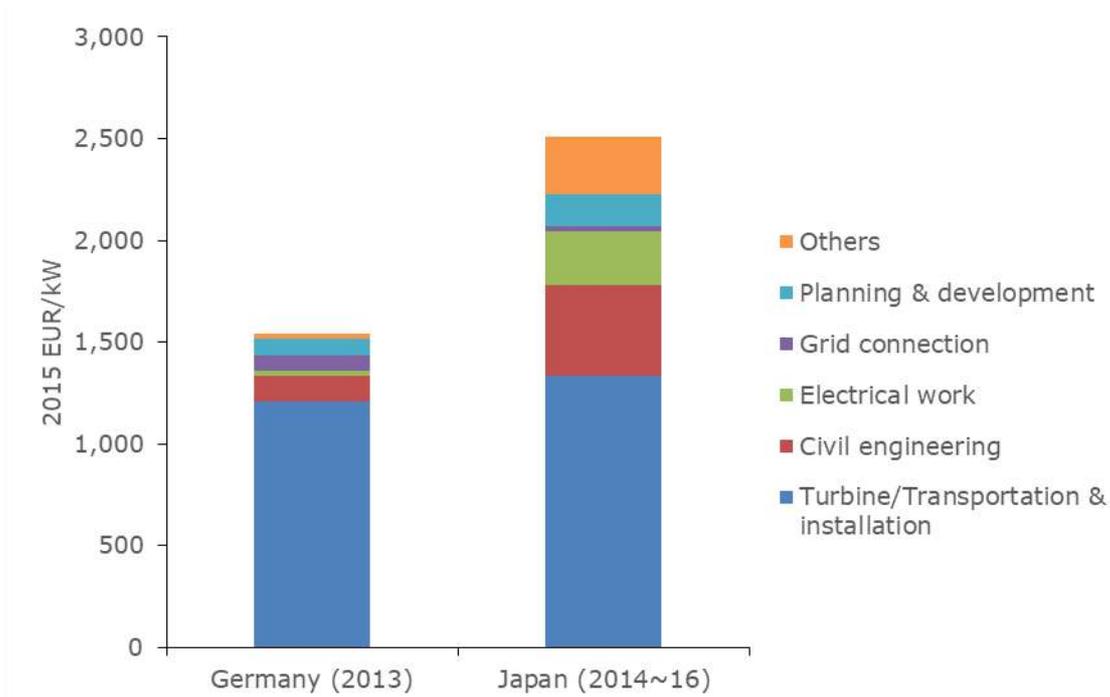
#### Investment costs in Japan: International comparison

Lastly, this section performs an international comparison of recent investment costs. Each country produces electricity under different conditions, that may cause differences in investment costs. For instance, in the United States, an average power plant has a capacity of 92 MW (2012), quite larger than the average in Japan.<sup>10</sup> In contrast, wind power plants in Germany are little different in size from those in Japan,<sup>11</sup> so the difference would not need to be taken into account. Despite differences in geographical conditions between Germany and Japan, the advanced industrial country in Europe is also relatively densely populated, with limited availability of land offering excellent wind resource quality these days. For these reasons, Germany is selected to compare its investment costs (average in 2013) with those in Japan between 2014 and 2016.

As obviously shown in Figure 15, investment costs are much higher in Japan than in Germany; developers in Germany invest 1,539 EUR/kW while those in Japan have to spend 2,510 EUR/kW, almost 1,000 EUR/kW more (on a 2015 EUR basis). It should be noted, however, that wind power plants covered by the German survey are equipped with turbines of 2.0 to 3.5 MW, larger than those installed in Japan.

<sup>10</sup> The average for the United States in 2012 reported by IEA Wind Task 26 (2015). According to the report, most of the projects have a capacity of 25 to 150 MW, much larger than the average in Japan, 12 MW.

<sup>11</sup> According to Leipziger Institute für Energie GmbH (2015), 43% of the wind power plants constructed in Germany between 2012 and 2014 are small-scale plants, with four turbines or fewer. The data offered by the report indicate that an average wind power plant constructed there during the period has an estimated capacity of 8 MW.



**Figure 15 Investment costs for wind power:**

**Comparison between Japan and Germany (in EUR, 2015-basis)**

Source: For Germany, Leipziger Institute für Energie GmbH (2014). Wind power plants covered by the German survey are equipped with turbines of 2.0 to 3.5 MW, larger than those installed in power plants in Japan.

Figure 15 shows the breakdown of investment costs. In Japan, costs for wind turbine/transportation & installation are higher, but only marginally. In contrast, in three items, civil engineering, electrical work, and other costs, there are significant differences between the two countries. These cost items are expenses in the domestic market.

That suggests the possibility that the differences in investment costs between Japan and other countries might be strongly influenced by domestic factors (locational, institutional, and industrial factors). Among the domestic factors, the size of power plants is not so much different between Japan and Germany, as the average for the latter stands at around 8 MW (2012 to 2014). The focus of the analysis should therefore be placed on other domestic factors.

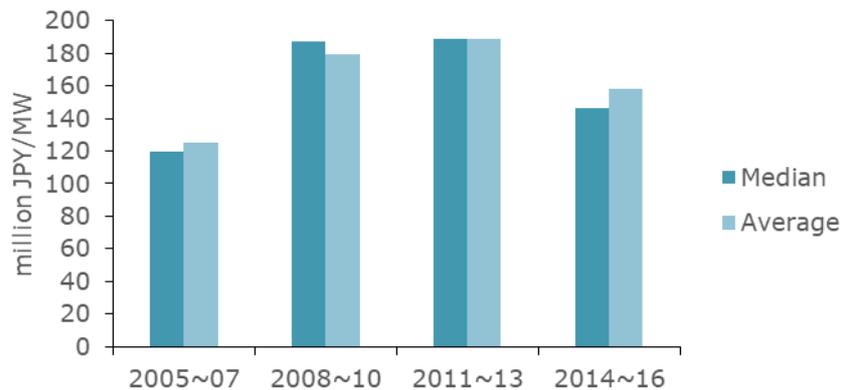
The following two chapters study recent changes in turbine, civil engineering, and electrical work costs, items that account for larger shares in investment costs, and analyze relationships with some factors that seem to impact costs.

## 4. Analysis of wind turbine costs

As seen in Figure 11, wind turbines costs constitute a major part of investments for wind power plants. In analyzing wind power costs, analysis of turbine costs is crucially important. Turbine costs are likely to be impacted by several institutional and industrial elements among the international and domestic factors. This chapter first presents changes of turbine costs over time and characteristics of turbines adopted in Japan, before examining the factors that influence turbine costs.

### Changes in turbine costs over time

Turbine costs account for the largest part of the investment costs for wind power. Except for the period between 2014 and 2016, turbine costs are responsible for around 60% of investment costs. Consequently, changes of turbine costs have significant impact on investments for wind power.



**Figure 16 Changes of turbine costs (median & average)**  
by commercial operation year  
Source: Renewable Energy Institute

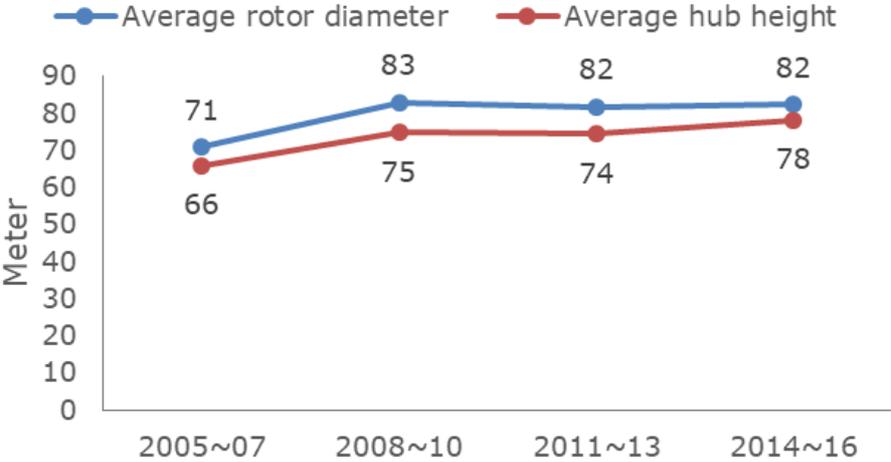
Figure 16 shows the wind turbine costs for wind power plants at the time they came into operation. Over the past ten years, two major changes can be observed. First, between 2008 and 2010, turbine costs exhibited a rapid increase. Turbines kept increasing between 2011 and 2013. The second change is a decline of turbine costs between 2014 and 2016, which amounted to some 40 million JPY/MW in the median. Taking into consideration that wind power plants in the sample of data collected for the period are smaller in size, larger power plants and major power producers might wield their bargaining power and procure turbines at lower prices. A wind power expert the authors interviewed commented, "In recent years, major power companies can procure turbines at 120 million JPY/MW or less."

### Characteristics of turbines adopted in Japan

As stated before, higher hub heights and larger rotor diameters are being introduced around the world to enable individual turbines to produce more electricity. However, the sample of data collected reveals that in recent years Japanese power plants do not always select the latest models of turbines adopted overseas.

The hub height, 66 meters on average between 2005 and 2007, has risen to 78 meters between 2014 and 2016 (Figure 17). However, it is still lower than the average hub height in Germany; 120 meters (Figure 4).

The rotor diameter, 71 meters between 2005 and 2007, also jumped by more than 10 meters to 83 meters between 2008 and 2010, before almost leveling off, another halt of enlargement. Figure 3 and Figure 4 , " the average rotor diameter in the two regions stood at some 80 meters around 2010, almost the same as in Japan, before longer blades were adopted for turbines to give them larger rotor diameters, around 100 meters on average in 2015.



**Figure 17 Average hub height and rotor diameter in the sample data**  
 Source: Renewable Energy Institute

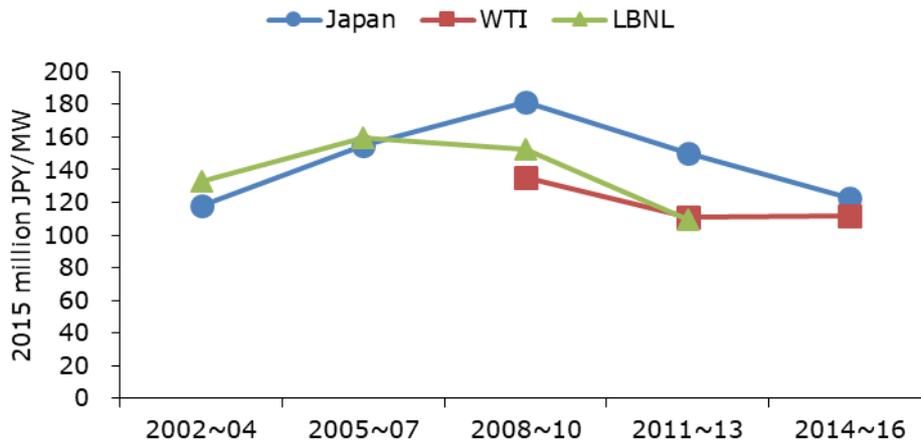
Indeed, in Japan, where the average speed of the wind is lower on an annual basis, a higher hub height and a larger rotor diameter should offer great advantages. However, some experts say, "In Japan, with quite extreme wind blowing in typhoons and other occasions, too high hubs and/or too large rotor diameters may result in overly severe requirements for design strength, and cost all the more." This problem of cost-effectiveness seems to be one of the issues lying behind the difficulty in adopting larger turbines.

However, in their lineups for the Japanese market in 2016, some turbine manufacturers include several models with a rotor diameter of 100 meters or more as part of their main offerings. With more facilities adopting these models, turbines in Japan would also grow larger in size to some extent.

**Factors that cause changes in turbine costs in Japan**

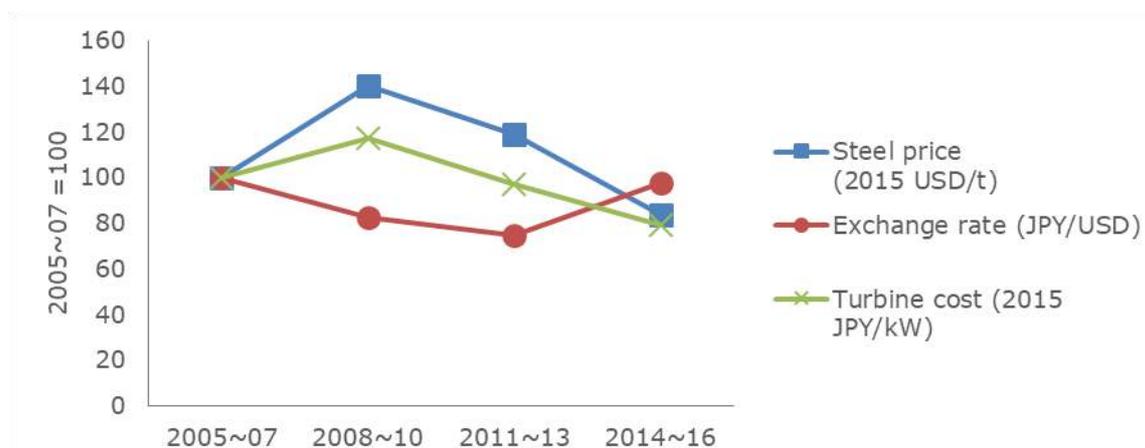
**(1) Comparison with international prices**

Because turbines are an internationally traded product, turbine prices are largely influenced not only by domestic but also by international factors. To examine impacts of international factors, this section compares costs for turbines in Japan with turbine prices in markets across the world. Here, however, comparing costs and prices of turbines as of their commercial operation year would be irrelevant, for two reasons. First, for Europe and the United States, most wind turbines are produced at home or in neighboring countries, and delivered in a short time, whereas Japan may have to import turbines with some time lag in delivery, as some nacelles used for them may be conveyed all the way from Europe or the United States. As a result, differences in time between construction work periods appear as another bias that makes such comparison irrelevant. Second, fluctuations in the foreign exchange rate also have some impact on costs with a time lag. Impacts of the exchange rate appear primarily when a contract is concluded, not at the commercial operation date of the turbine. For these reasons, international comparison should use costs and prices of turbines as of a contract/transaction being concluded to better reflect the realities.



**Figure 18 International comparisons of turbine costs and prices as of contract/transaction years**

Source: Adapted from Renewable Energy Institute, BNEF (2015), and Wisner and Bolinger (2016)  
 Note: Figures for Japan are weighted averages of turbine costs as of contracts being concluded, represented in the value of the yen in 2015. WTI refers to the Wind Turbine Price Index of BNEF. As WTI is based on prices of turbines as of delivery, the data for the graph are moved backward by one year, assuming that contracts are concluded one year before the delivery. LBNL represents average transaction prices of turbines in the United States. LBNL often includes not only prices of turbines, but also costs for transportation, limited warranty, and services.



**Figure 19 Changes of turbine costs, steel prices, and exchange rates as of contract years**

Source: Adapted from Renewable Energy Institute, Japan Metal Daily, and IMF  
 Note: Steel prices, exchange rates, and turbine costs are indexed with those between 2005 and 2007 set as 100. The steel price is the average of heavy plate prices per ton (in USD, 2015-basis).

Figure 18 shows contracted costs and prices of turbines. WTI is a global price index, and LBNL tracks transaction prices in the United States. Turbine prices in the United States should not be compared directly with those in Japan, as the former includes various incidental costs in contracts. It is also because in the United States power plants are developed on a much larger scale. Between 2002 and 2007, nonetheless, transaction prices in the United States were almost at the same level as turbine costs in Japan. "Figure 19 Changes of turbine costs, steel prices, and exchange rates as of contract years" indicates impact of changes of steel prices and the exchange rates on turbine costs in Japan. Turbine costs generally tend to follow steel prices.

That raises the question why, between 2008 and 2013, turbine costs in Japan diverged so widely from international prices. Turbine costs in Japan stayed above not only transaction prices in the United

States but also WTI all through the period. The most significant contributor that helped turbine costs in Japan diverge from global turbine prices from 2008 seems to be found in institutional factors at home. The Building Standards Act of Japan, revised in 2007, requires that wind power plants satisfy stringent earthquake-proof criteria, unique to the country.<sup>12</sup> Turbines built for power generation in Japan are required to be strong enough to endure such severe conditions. In terms of strength for bearing burdens of extreme wind in typhoons and other occasions, the same conditions as in Europe apply. However, additional strength is required to resist earthquakes, which requires some modification to design of turbines, with the risk of cost increases.

The Building Standards Act also requires that steels and other materials used for major structures of turbines satisfy quality specified in sections of the Japanese Industrial Standards designated by the Minister of Land, Infrastructure, Transport and Tourism. Some manufacturers that the authors interviewed said materials that meet the conditions can be produced only by limited factories as tailor-made products for the Japanese market.<sup>13</sup>

Nonetheless, prices of turbines in contracts concluded between 2014 and 2016 are falling down near the global WTI index. Declines of cost during the period may be attributable to institutional factors at home. With the FiT being enforced in July 2012, growth of installed capacity of wind power, after temporary slowdowns, have been picking up, only moderately, a sign of reinvigoration in the Japanese market. New wind power capacities installed on an annual basis increased again in 2014 and 2015 to 130 MW and 240 MW, respectively (JWPA, 2017). Enhanced attractiveness of Japan as a wind power market after the introduction of the FiT encourages turbine producers overseas to enter the country again. During interviews, several turbine producers said, "Amid increasingly fierce competition among turbine manufacturers, higher prices are hard to ask for, even with increased procurement prices for electricity under the FiT. The FiT itself offers us no opportunity to achieve higher profitability."

## (2) Relation with the size of power plants

Next, this section examines the relation between the size of plants and turbine costs. As shown in Figure 16, large differences appeared in turbine costs around 2008. Here, turbines coming into operation in 2008 and later are selected to study the relation between their size and costs. It is found that, as in the case of investment costs, the logarithmic model fits better than the linear one, with a moderate level of negative correlation at a coefficient (R) of 0.406, although statistically insignificant at a significance level of 5% ( $n = 19$ ,  $p$ -value = 0.085).

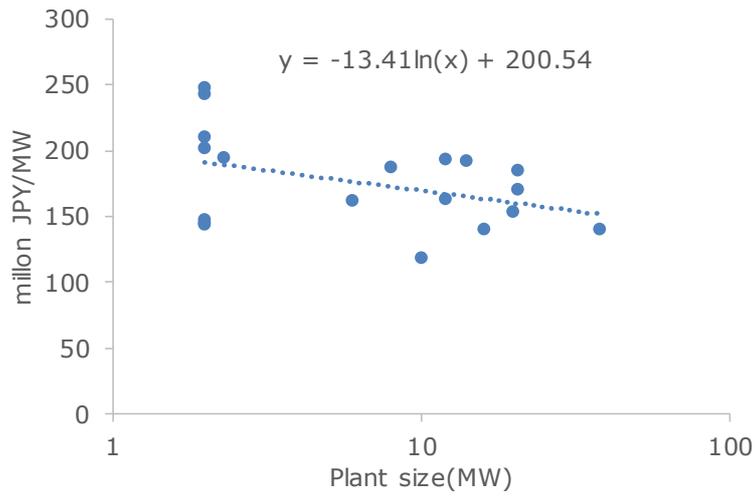
If any logarithmic relation exists between the size and cost, then, in comparison with a single turbine of 2 MW, a wind power plant equipped with another four turbines to have a capacity of 10 MW, or five 2-MW units, could achieve significant reductions of turbine costs. However, four additional turbines, nine units of 18 MW in total, would only deliver a smaller cost reduction effect than as many turbines installed to increase the number of units from one to five.

---

<sup>12</sup> Specifically, the revised Act requires wind turbines higher than 60 m to satisfy earthquake-resistance standards comparable to those for skyscrapers. They are required to undergo a review by a designated performance evaluation organization, before being approved by the Minister of Land, Infrastructure, Transport and Tourism. Influences made by the revision are summarized by Hayashi (2008).

<sup>13</sup> Building Standards Act: Article 37 (Quality of construction materials)-1 "Wood, steel, concrete, and other construction materials designated by the Minister of Land, Infrastructure, Transport and Tourism as used for foundations, main structures, and other parts of buildings specified by a Cabinet Order as critical for safety, fire prevention, and hygiene reasons (hereinafter referred to as 'designated construction materials' in this Article) shall fall under any of the following items:

1. The quality satisfies sections of the Japanese Industrial Standards or the Japanese Agricultural Standards designated by the Minister of Land, Infrastructure, Transport and Tourism for each of the designated construction materials."



**Figure 20 Relation between the size of power plants and turbine prices  
(plants coming into commercial operation in 2008 and later)**  
Source: Renewable Energy Institute

## 5. Analysis of civil engineering and electrical work costs

### Changes of costs over time

Civil engineering costs include costs for constructing wind power plants and building roads for transportation to construction sites. Electrical work costs are composed of costs for laying wires over the premises, and installing and connecting transformers and other necessary equipment. Costs for laying power lines should be classified as grid connection costs. However, some power plants include the costs in their electrical work costs. In this analysis, electrical work and grid connection costs are collectively referred to as "electrical work and connection costs." Civil engineering and electrical work costs are the two largest items after turbine costs (Figure 11). Unlike turbine costs, the two items are impacted by several domestic factors that are intertwined.

Changes of these costs are shown in Figure 21 and Figure 22. Costs per kW have been increasing over time. Until 2013, civil engineering costs had been rising moderately. Then, between 2014 and 2016, civil engineering and electrical work costs both made rapid increases of as much as 40 million JPY/MW or more.

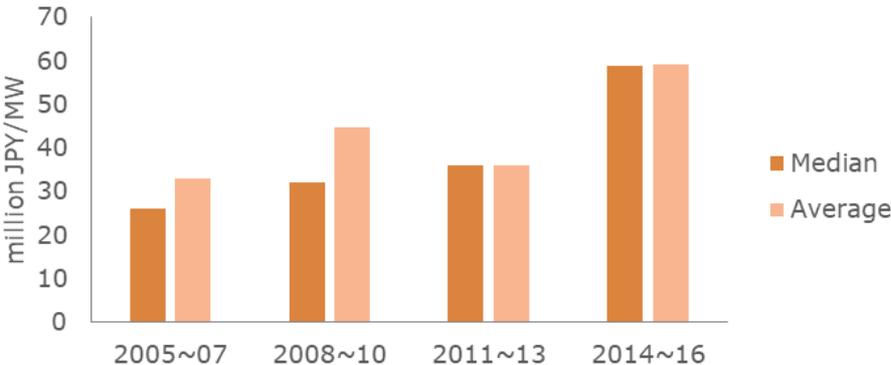


Figure 21 Changes of civil engineering costs (median & average)

s

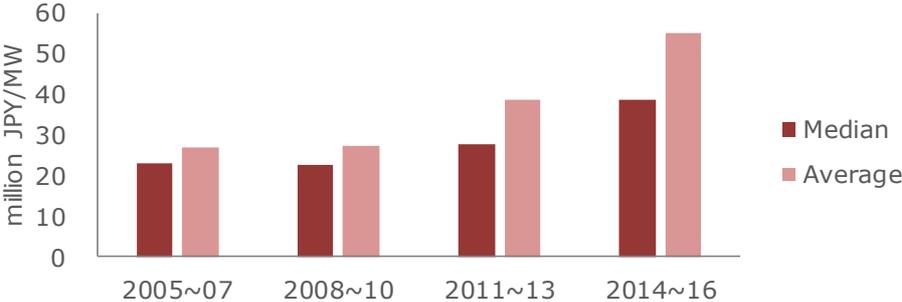


Figure 22 Changes of electrical work and connection costs (median & average)  
Source: Renewable Energy Institute

Analysis of cost factor increases

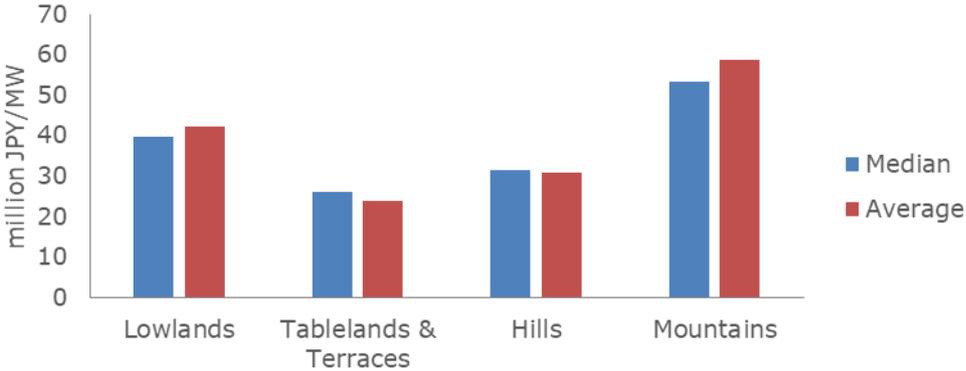
The focus is placed on factors that contributed to these sharp increases in civil engineering and electrical work cost between 2014 and 2016. This section examines possible domestic factors related to these two categories of costs (Table 7).

**Table 7 possible factors for cost rise**

Factor	Issues to be examined
Locational factor	Civil engineering: Whether any geographical features may contribute to increased costs for preparing sites. Electrical work: Whether power plants are located somewhere too far from a grid connection point.
Industrial factor	Whether too small a size of power plants, 5 MW on average between 2014 and 2016, may have any influence.
	Whether so-called reconstruction work demand and Olympics effect may push up labor costs, material prices, and/or unit construction costs.
	Whether prolonged construction periods may have any influence.

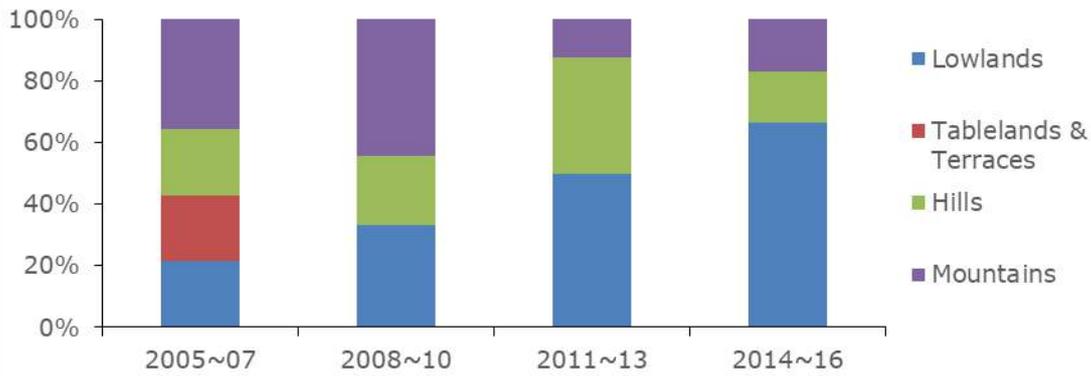
(1) Locational factors

The first issue is whether any specific geographical features may impact construction costs. Civil engineering costs may increase when power plants are constructed in mountainous areas, as costs add up for, among others, building roads to deliver turbines, and clearing forests to prepare sites. Aggregating civil engineering by geographic feature, as shown below in Figure 23, demonstrates that indeed costs tend to be larger among power plants built in mountains.



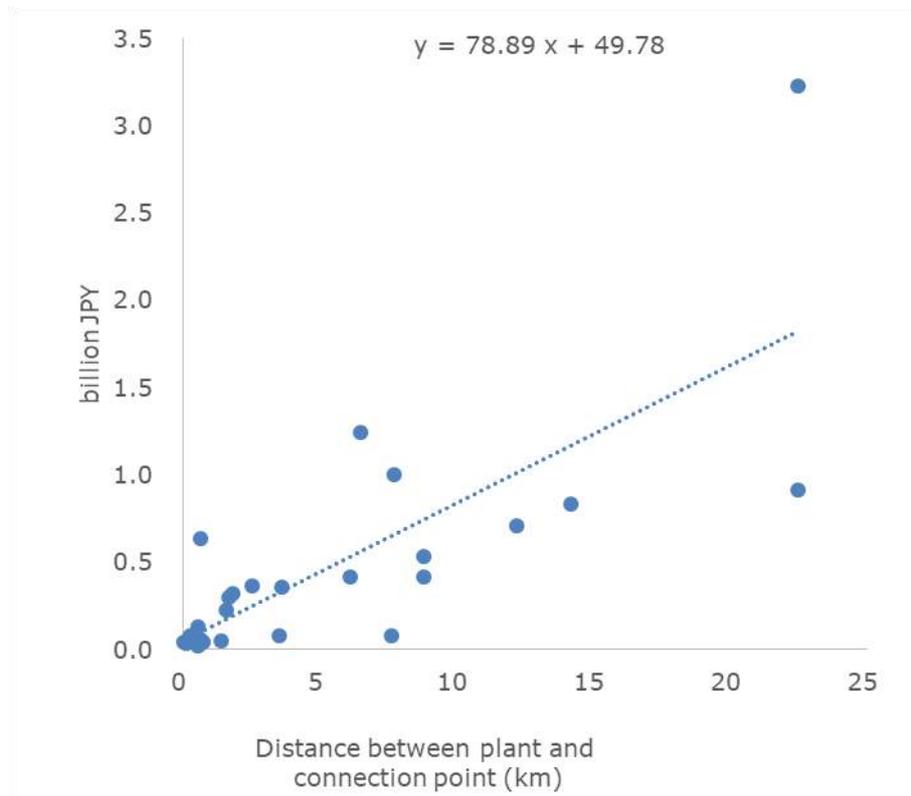
**Figure 23 Civil engineering costs by type of geographic feature**  
Source: Renewable Energy Institute

Then, examining in which geographical features wind power plants were built between 2014 and 2016, it can be observed, as shown Figure 24, that most of them were built in lowlands. That nullifies the assumption that locational factors are mainly responsible for increased civil engineering costs between 2014 and 2016.

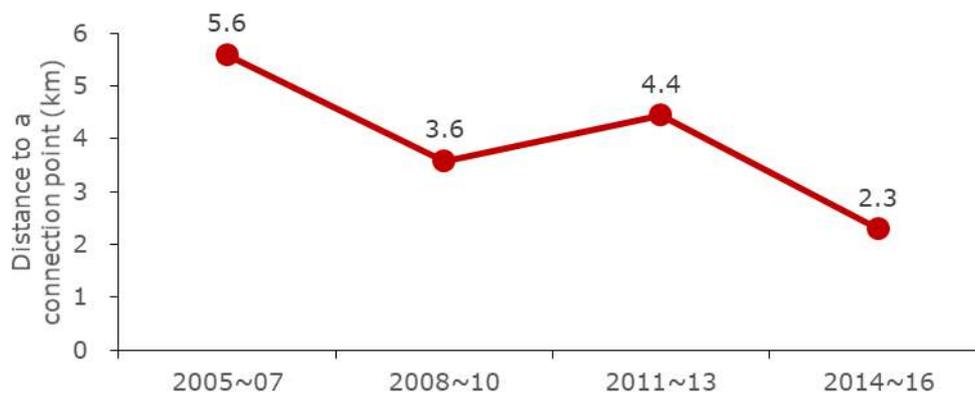


**Figure 24 Changes in locational conditions by period**  
Source: Renewable Energy Institute

Electrical work and connection costs may be impacted by locations. When a power plant is constructed far away from the existing grid network, or near a network short of available transfer capacities (ATC), a longer power line must be laid to access another network located farther away to secure larger ATCs. That would drive electrical work and connection costs up. Indeed, Figure 25 shows this category of costs is highly correlated with the distance of power line ( $R = 0.78$ ,  $n = 31$ ,  $p\text{-value} = 0.000$ ). However, the average distance from the power plants coming into operation between 2014 and 2016 to a grid connection point is shorter than that in any other period (Figure 26).



**Figure 25 Correlation between electrical work and connection costs and the distance from a grid connection point**  
Source: Renewable Energy Institute



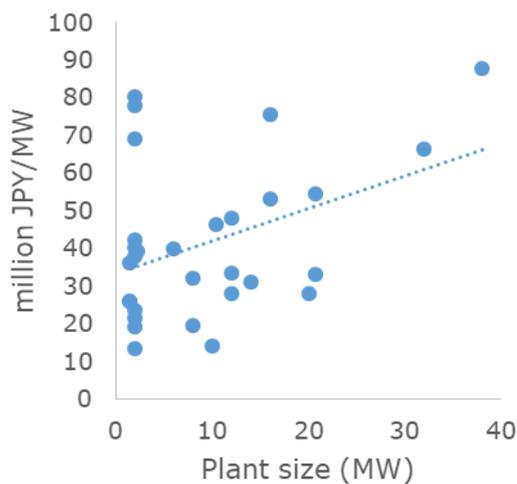
**Figure 26 Average distance to a grid connection point**

Source: Renewable Energy Institute

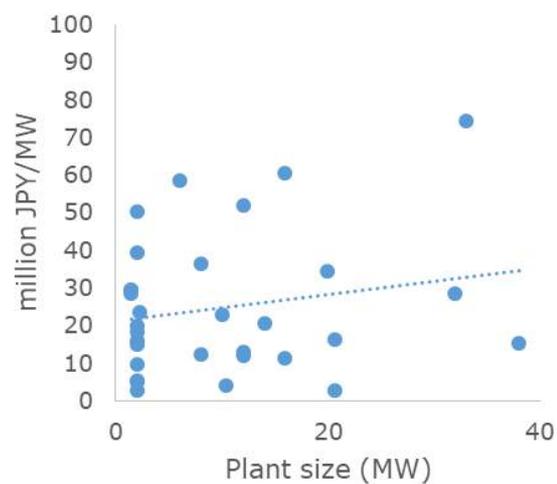
(2) Size of power plants

Among the data collected a large share of the power plants which came into operation between 2014 and 2016 are smaller in size (Table 4). Given that smaller plants cost more for civil engineering and electrical work costs per MW, the small average size among the plants coming into operation during this period would be one of the factors that made them costlier.

Figure 27 indicates the relationship between the sizes of plants and their costs per MW. Little correlation exists between electrical work costs per turbine and the size ( $R = 0.20$ ,  $N = 31$ ,  $p\text{-value} = 0.284$ ). Civil engineering costs per MW tend to increase marginally with the size of power plants ( $R = 0.39$ ,  $N = 30$ ,  $p\text{-value} = 0.029$ ). This reveals that the smaller size of power plants cannot explain the higher civil engineering and electrical work costs per MW, at least among those coming into operation between 2014 and 2016.



**Figure 27 Relationship between civil engineering costs and the size of plants (left)**



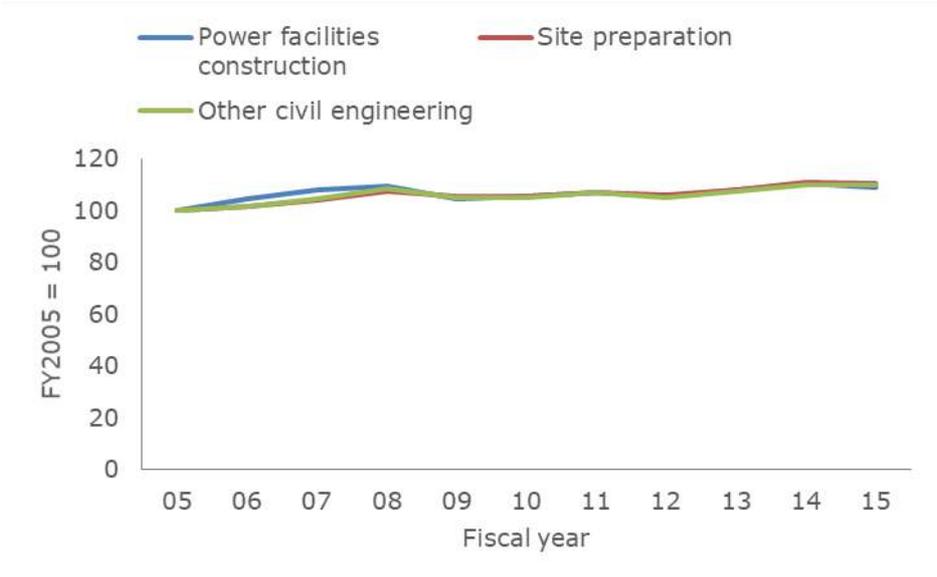
**Figure 28 Relationship between electrical work costs and the size of plants (right)**

Source: Renewable Energy Institute

(3) Changes of labor costs per hour, material prices, and construction work costs per turbine

Labor costs per hour, material prices, and construction costs per turbine fluctuate along with changes in supply and demand in the construction market, which may impact engineering and electrical work costs per MW for wind power plants. This section examines changes of labor costs per MW and material prices, and trends of related construction costs.

General construction costs can be referred to the "construction cost deflators" (FY2005 = 100), released by the Ministry of Land, Infrastructure, Transport and Tourism. The index shows that construction costs likely to be related to wind power plants (power facilities construction, site preparation, and other civil engineering work) increased by 3 to 5% from FY2010 to FY2014 and FY2015 (Figure 29).

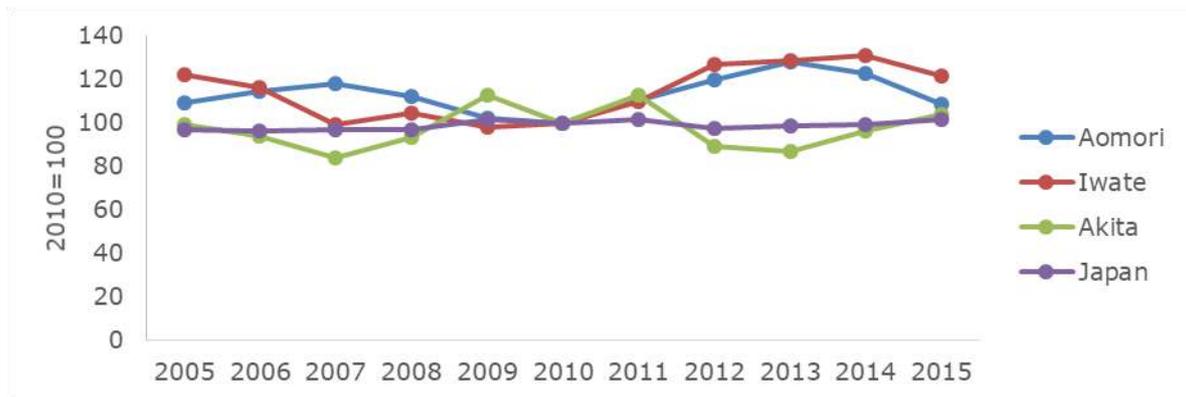


**Figure 29 Construction costs deflator**

Source: Adapted from the Ministry of Land, Infrastructure, Transport and Tourism (2016), "Construction Costs Deflators (FY2005 = 100)"

Next, labor costs per hour, seen in changes in hourly wages among construction (incl. electrical work) companies (with five employees or more) decreased by three percentage points nationwide from 2010 to 2012, before increasing by six percentage points to 2015 (Figure 30). In the end, the costs rose by three percentage points from 2010, that is far from a significant increase throughout the entire period.

Among three Tohoku prefectures where many power plants are located, Iwate, Aomori, and Akita, the first two prefectures saw increases in hourly wages between 2012 and 2014. In Iwate, one of the prefectures severely damaged by the Great East Japan Earthquake, wages seem to have been impacted by the reconstruction work demand. In contrast, Akita, situated along the Sea of Japan, saw no significant change in hourly wages.

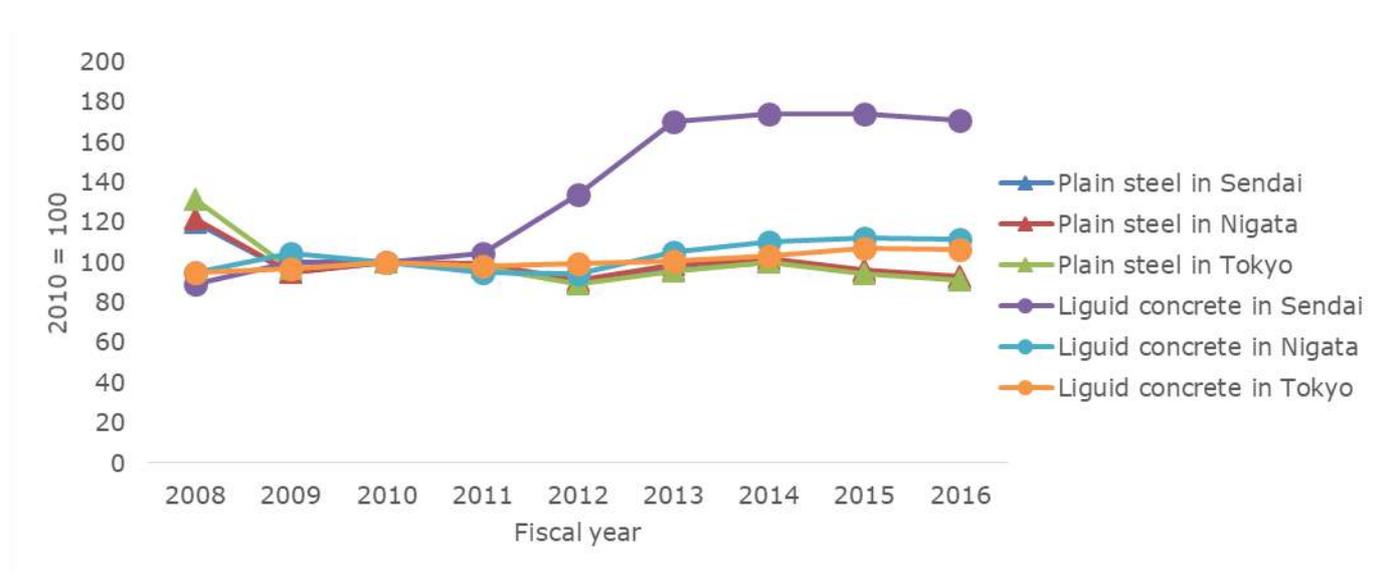


**Figure 30 Changes of hourly wages among constructors (with 5 employees or more) (2010 = 100)**

Source: Adapted from the Ministry of Health, Labour and Welfare, and Aomori, Iwate, and Akita Prefectures, "Monthly Labour Survey"

Note: Hourly wages are the total amount of cash earnings divided by the total of actual working hours.

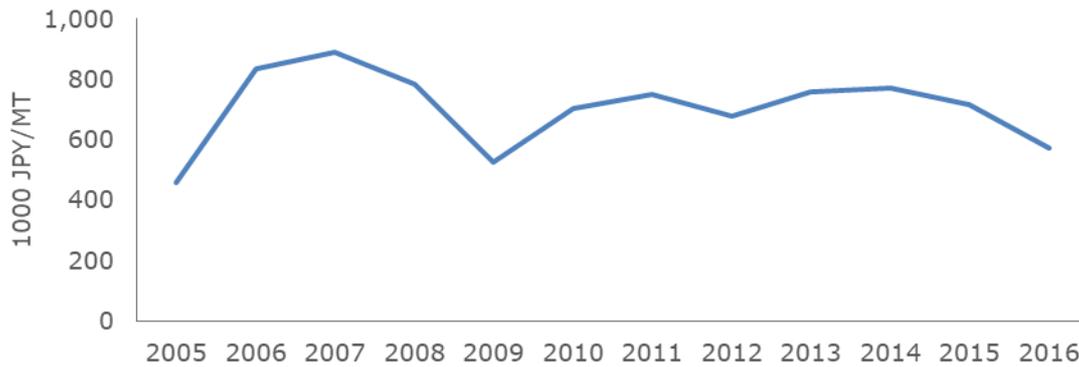
Finally, material prices must be examined. Among materials used for civil engineering work for wind power plants, steel and concrete are major. Indexes of prices of these construction materials in individual cities are released by the Economic Research Association. Here, to compare impacts among Tohoku, the region along the Sea of Japan, and the rest of Japan, three cities, Sendai, Niigata, and Tokyo are selected and prices of plain steel and liquid concrete are examined there. It is found that prices of plain steel fell from 2010 in all three cities. In contrast, they all saw price increases in liquid concrete from 2010. Prices rose by some 10% in Tokyo and Niigata, and by as much as some 70% in Sendai from the year. The sharp increase of liquid concrete prices in Sendai seems to be related to the reconstruction work demand after the Great East Japan Earthquake.



**Figure 31 Price indexes of construction materials (plain steel & liquid concrete) for cities**

Source: Adapted from the Economic Research Association by the Renewable Energy Institute

Next, for electrical work, one of the main materials used is power cable, which main constituent material is copper. Figure 32 plots changes of copper prices in Japan between 2005 and 2016. It is clear that copper prices were at their highest between 2006 and 2008, before leveling off from 2010. That is, increases of electrical work costs per MW between 2014 and 2016 cannot be explained by prices of materials for power cable.



**Figure 32 Changes of copper prices in Japan (annual average)**

Source: Adapted from the Japanese Electric Wire & Cable Marketers' Association by Renewable Energy Institute.

The analyses above have found no significant increase of labor costs per hour or material prices on a nationwide basis. For civil engineering and electrical work costs, the construction work deflators increased merely by several percentage points. Among regions, however, large differences are observed. Especially in parts of the Tohoku region along the Pacific coast, labor costs and prices of some materials rose sharply, probably because of reconstruction work demand after the Great Earthquake. That is the likely the cause of rapid increases in construction costs there. In parts of the Tohoku region lying along the Sea of Japan, little impact has been felt from any reconstruction work demand. In conclusion, rapid increases of civil engineering work costs between 2014 and 2016 seen in data collected may be explained partially by increased labor costs and material prices, or industrial factors, while they can explain little about increased electrical work costs and other costs.

#### (4) Changes of construction periods

Construction periods significantly impact construction costs. A longer construction period costs more to retain workers and equipment. Once any clear relationship is found between construction periods and costs, power plants built in different years could be compared between them in terms of their construction periods to roughly estimate their impacts on increases of construction costs between 2014 and 2016. Among power plants with several turbines, the construction period per turbine is shorter than among those with a single turbine, as more than a single facility can be built simultaneously.<sup>14</sup> This section, selecting power plants equipped with fewer turbines, compares average construction periods per turbine and civil engineering costs per turbine among them. Here, the construction period of a turbine is defined as months from the day the construction work gets started through the day it is put into operation (Table 8.)

---

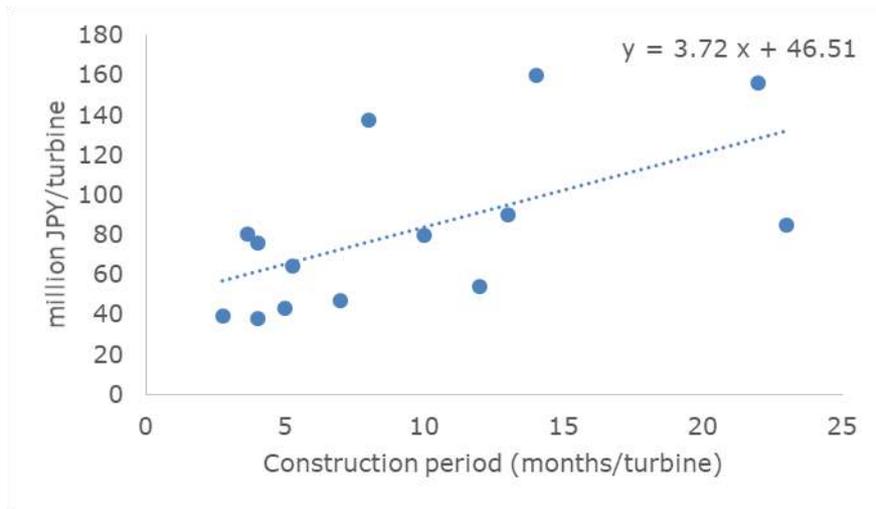
<sup>14</sup> In theory, power plants with more turbines could be compared to examine the relationship between construction periods and costs per turbine once they are grouped into those with the same number of turbines. With unavailability of any sufficient size of samples for reasonable analysis, no such comparison is performed here.

**Table 8 Timetable for construction of a single turbine with a capacity of 1.5 MW (Ex.)**

No.	Wind Power Plant: Construction Schedule		1st Month	2nd Month	3rd Month	4th Month	
0	Milestone		Construction started	Power received		Transferred	
1	Civil engineering	Roads & sites	●				
		Foundation for turbines	▶	▶	●		
		Premises			▶	●	
2	Electrical work	Cables for high-voltage power		▶	●		
		Switchboards & cubicles		▶	●		
		Cables & earth connection	▶	▶	▶	●	
3	Wind turbines incl. overland transport	Towers			▶	●	
		Nacelles & rotors			▶	●	
		Controllers			▶	●	
4	Measuring equipment	Measuring equipment installed	▶	▶	▶	●	
5	Test & inspection	Inspected (adjusted) by manufacturer			▶	●	
		Voluntary pre-service inspection		▶	▶	▶	●
		Test run			▶	▶	▶

Source: NEDO (2008)

▶ :Started ● :Finished



**Figure 33 Relationship between construction periods and civil engineering costs:**

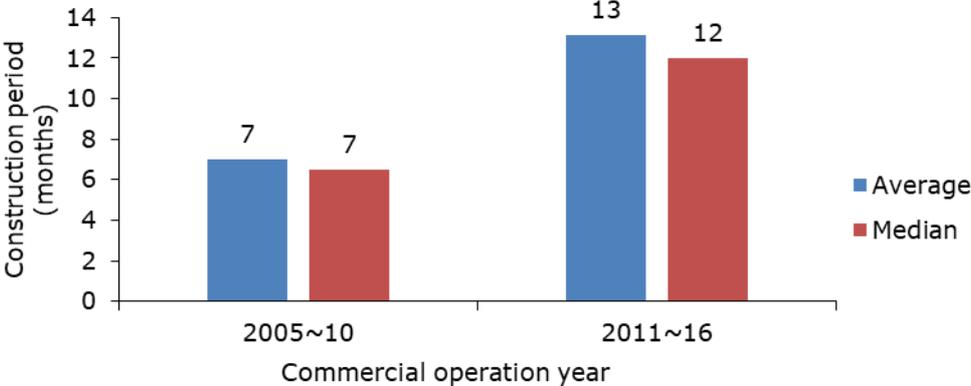
**Power plants with four turbines or fewer**

Source: Renewable Energy Institute

Construction periods and civil engineering costs show a moderate positive correlation between them ( $R = 0.591$ ,  $n = 14$ ,  $p\text{-value} = 0.026$ ). That suggests that longer construction periods contribute to higher civil engineering costs per turbine. In contrast, little correlation is seen between electricity work costs and construction periods.

Then, how large are the differences in the construction period between years? Here again, power plants equipped with a single turbine are selected to examine construction periods. They are divided into two groups, those coming into operation by 2010 and those coming into operation after that year, and construction periods are compared between them (Figure 34). In the first group, the average construction period was 7 months, while in the latter, it was almost double, 13 months. According to NEDO (2008), a standard wind power plant with a single turbine is constructed in some three months. In practice, some plants may need longer time to be finished when tests and inspections take longer than planned (one or two more months) to be completed, and/or when certain locational conditions require construction of additional roads for access. Some people working in the wind power industry say that in any event, very few power plants need 12 months or more.

As observed above, the construction period is positively correlated with civil engineering costs, and it has been getting longer in recent years. That leads to the assumption that such a rapid increase of the construction period may have given not negligible impact on increases of civil engineering costs per turbine.



**Figure 34 Construction period for wind power plants equipped with a single turbine**  
 Source: Renewable Energy Institute

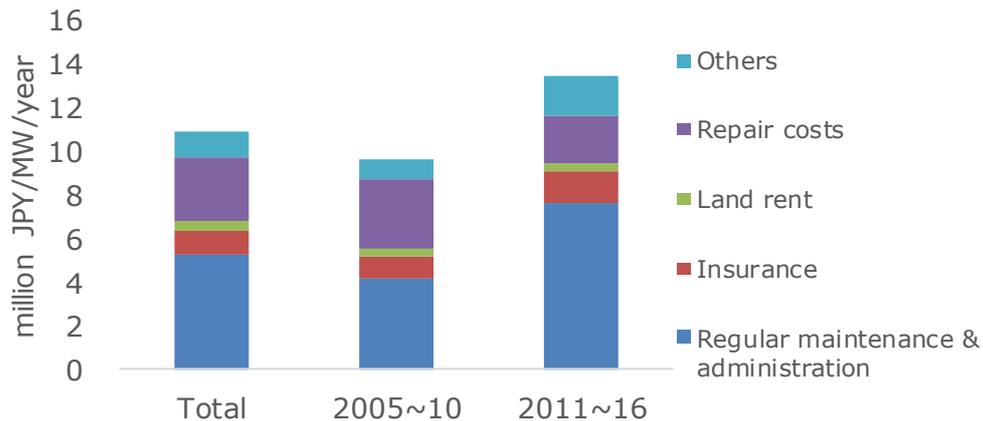
The analyses above indicate that the rises of civil engineering costs between 2014 and 2016 are in part attributable to increased labor costs per hour and material prices. Especially, they suggest these factors had greater impacts on parts of the Tohoku region lying along the Pacific coast. In contrast, no significant impact is observed along the Sea of Japan. During interviews constructors engaged in work for wind power plants said, "Indeed labor costs per hour and material prices increased, but they do not have so much influence on the total construction cost." Rather, they stated, "In Tohoku, with scarcity of labor and heavy machines, local contractors have found they have the upper hand." That may be a factor that drives up prices. As another possible contributor to the increased civil engineering costs, this research has also found prolonged construction periods. No specific factor lying behind that has been identified.

For electrical work and connection costs, this research has examined their relationship with the distance from an interconnection network and prices of copper, the main constituent material for power cable, but found that neither can explain the rapid cost increases between 2014 and 2016, leaving any contributors unknown.

## 6. Analysis of operation and maintenance costs

### O&M costs and their breakdown

Another important cost item, along with investment, is operation and maintenance (O&M) costs. Wind power plants generate electricity on a great number of machines, which must be operated and maintained in an appropriate manner once built and put into operation. For that purpose, power plants must perform day-to-day maintenance services and regular inspections, and in addition, must prepare some contingency arrangements, including insurance, to deal with any emergency, such as machine malfunctions.



**Figure 35 O&M costs (median)**

Source: Renewable Energy Institute

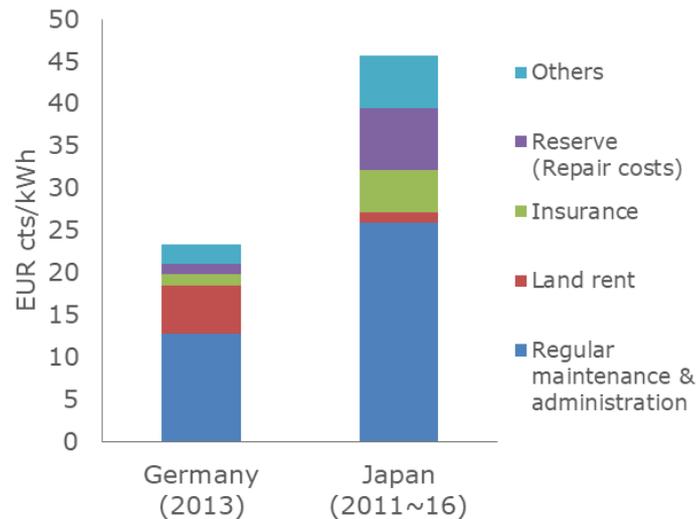
For this research, actual O&M cost data were collected from 33 plants, which exclude those planned but have not come into operation. Among them, total O&M costs stand at 11 million JPY/MW/year in median and 12 million JPY/MW/year on average. In the total costs, "regular maintenance & administration costs" account for the largest part. They are ordinary costs for day-to-day operation management services and regular inspections. In addition, land rents and insurance premiums are also treated as ordinary costs. In contrast, repair costs refer to irregular costs paid to deal with troubles in equipment beyond the coverage of the manufacturer's guarantee. In consequence, a significant dispersion is found among the costs, as some plants have paid little for repair so far.

Differences in O&M costs between younger and older power plants were examined by dividing them into two groups, those coming into operation between 2005 and 2010 and those getting started after that year, to aggregate the costs in each group. It is found that repair cost more in the former. It seems quite natural that older power plants have to pay more for repair. Another item, regular maintenance & administration costs, is much larger, almost double, among the power plants coming into operation between 2011 and 2016. In the latter group, insurance premiums also increase, though they represent merely a small part of total costs.

### International comparison of O&M costs

Where does Japan stand in the international comparison of O&M costs? As done before for investment costs, this section compares Japan and Germany in O&M costs (average). In Germany, O&M costs are reported on a kilowatt-hour basis. Here, costs in Japan are also converted into the same unit.

It is observed that wind power plants in Japan spend almost double for O&M than those in Germany (Figure 36). Categorized by item, all the costs other than land rent are much larger in Japan.



**Figure 36 Comparison between Germany and Japan in O&M costs**

Source: For Germany, see Leipziger Institute für Energie GmbH (2014).

Note: O&M costs in Japan refer to the median for the period between 2011 and 2016, calculated with the IRR set at 4.6%, the same as Germany's, the capacity factor at 26%, the value after the introduction of the FiT, and one euro at 130 yen.

### Factors that impact O&M costs

O&M costs are composed of several items that are influenced quite differently by some factors, which further complicate analyses. This chapter focuses on the most significant cost item, regular maintenance & administration costs.

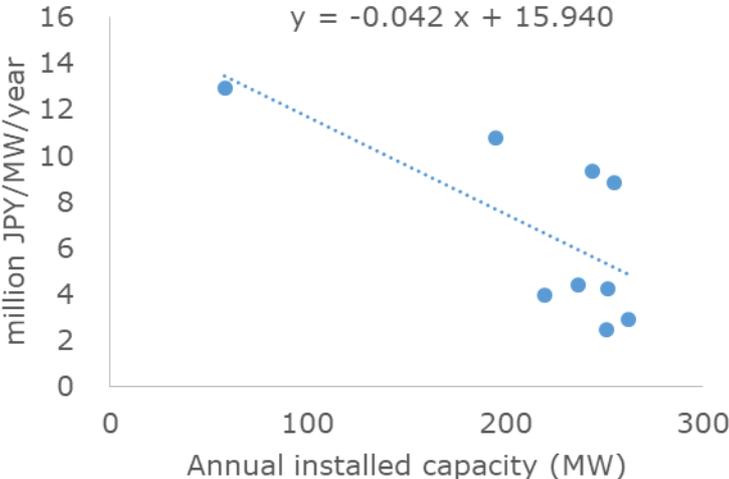
Three factors are examined; (1) relationship with the size of market, (2) with the size of power plant, and (3) with parties responsible for O&M.

#### (1) Relationship between the size of market and costs

In its report, the Study Group for Enhancing Competitiveness of Wind Power Generation, set up by the ANRE of the Ministry of Economy, Trade and Industry, pointed out the possibility that costs may be impacted by the size of the wind power market. It was reported, in Japan, "[...] the limited installed capacities only offer weak industrial foundations for maintenance service providers, who have lagged behind in efficiency and streamlining." (The Study Group for Enhancing Competitiveness of Wind Power Generation (2016), p. 15). Some experts that the authors interviewed said, "Despite its small size of market, Japan has introduced many models of wind turbines. For a small number of units in each model, maintenance service providers must learn different maintenance techniques and keep incompatible components in storage, which pushes up maintenance costs." The Study Group pointed out the small size of Japan's wind power market as a source of weakness in the foundation of the maintenance service industry. The relationship could be demonstrated by comparing maintenance costs in other countries and their industrial structures. That would require more in-depth research, beyond the coverage of this report. Meanwhile, the experts mentioned above, who also pointed out the smallness of Japan's market, suggested the possibility that O&M costs may differ depending on the relative number of models of wind turbines adopted.

This section assumes that in a year when a larger capacity is installed, a larger number of wind turbines of a model are built, which pushes down regular maintenance & administration costs. This hypothesis could be examined by studying the relationship between capacities installed in a year and regular maintenance & administration costs for power plants coming into operation that year. They show a large negative correlation between them ( $R = 0.704$ ,  $n = 9$ ,  $p\text{-value} = 0.034$ ).

It should be noted, however, that this analysis uses a limited number of data, and excludes three years with data available from a mere single sample of cost data (2008, 2013, and 2014). Therefore, it would be premature to conclude, based solely on this analysis that a larger amount of installed capacity helps push down regular maintenance & administration costs. Nonetheless, the relationship between installed capacities and costs remains worth of further investigations.



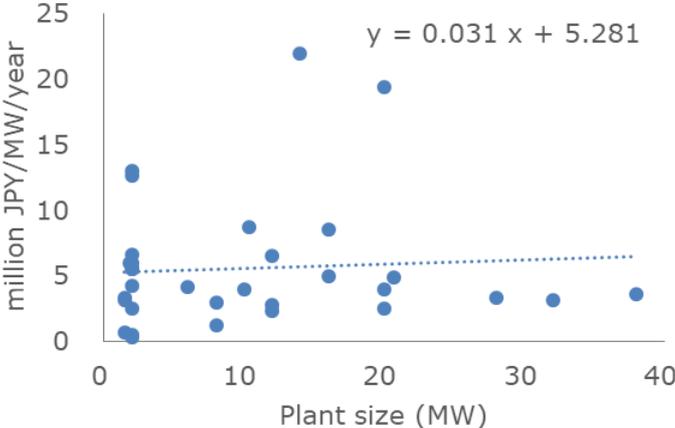
**Figure 37 Capacities installed on an annual basis (2005–2016) and regular maintenance & administration costs (average)**

Source: Renewable Energy Institute

Note: Three years with data available from a mere single power plant (2008, 2013, and 2014) are excluded from the analysis.

(2) Relationship with the size of power plants

Another factor that may influence regular maintenance & administration costs is the relationship with time and distance. Power plants are operated and managed by workers, and their working hours is a significant element. It is assumed that when a single administrator is responsible for a larger number of wind turbines, regular maintenance & administration costs per MW would decline. In practice, power plants with many wind turbines are operated by staff members designated for each wind turbine, while those with fewer turbines are grouped in their areas and managed by those responsible for each area. In the latter case, administrators may need to move over a longer distance, for all the longer time. In turn, larger power plants, with administrators always stationed around them to operate a larger number of turbines, may cost less per kW for regular maintenance & administration. The data available for this research show little correlation between the size of power plants and the costs (R=0.06).



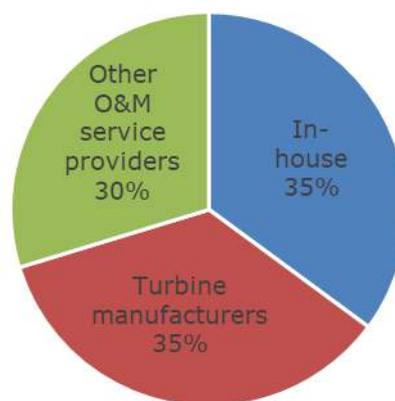
**Figure 38 Size of power plants and regular maintenance & administration costs**

Source: Renewable Energy Institute

### (3) O&M costs by type of O&M service providers

O&M services can be supplied by different types of entities. Under most contracts, turbine manufacturers offer a warranty against defects and/or a guarantee of a specific availability factor, among others, for two years from the date of a turbine starting operation, and they are responsible for its O&M. After that period, O&M services can be managed in three different players: (1) power producers operate and maintain plants in-house; (2) turbine manufacturers continue providing O&M services; and (3) O&M services are outsourced to O&M service providers for wind power plants.

When power producers were asked who was responsible for O&M after the expiration of a warranty, their responses were split almost equally between the three groups (Figure 39). Among the power plants, 35% were operated and maintained by power producers in-house, while as many were cared for by turbine manufacturers. The remaining 30% of them had their O&M services outsourced to O&M service providers.

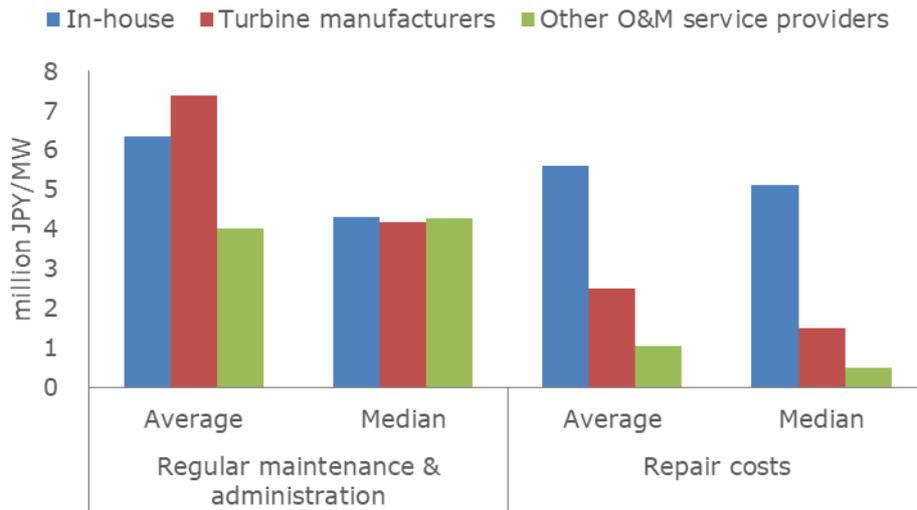


**Figure 39 Share of O&M service providers**

Source: Renewable Energy Institute

Next, who is responsible for O&M is compared among power plants to see what difference(s) may appear in their general O&M costs. The average cost is higher when turbine manufacturers or power producers provide O&M services in-house. However, little difference is observed in the median between the ways O&M services are carried out (Figure 40). It should be noted that, among power producers who operate and maintain their wind turbines in-house, those with 20 turbines or more only spend roughly half the average for the work. That suggests the possibility that differences in regular maintenance & administration costs may not reflect the ways O&M services are dealt with, but rather the number of wind turbines they manage and/or the amount of experience they have.

In contrast, large differences are observed in repair costs. The data collected for this research have indicated that power producers working themselves for O&M pay more for repair. In addition, repair costs differ a lot even among power producers who manage a larger number of wind turbines in-house, and they may not simply change in proportion to the number of turbines.



**Figure 40 Regular maintenance & administration and repair costs**

**by type of O&M service providers**

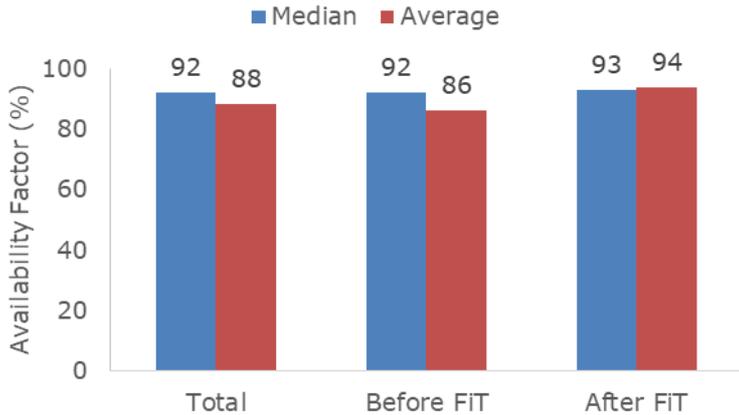
Source: Renewable Energy Institute

## 7. Analysis of the actual amount of electricity generated

When measuring the economic profitability of wind power, the actual amount of electricity generated has a great significance. What is most significant among the elements that determine performance of power generation is the availability factor, followed by the capacity factor.

### Availability factor

The availability factor of a power plant indicates how many days a year it is available for operation. A larger availability factor means a wind power plant can work for more days and, in consequence, is likely to produce a greater amount of electricity. This report refers to Uchida et al. (2008) to aggregate data of the system availability factor<sup>15</sup> between power plants.



**Figure 41 System availability factor**  
Source: Renewable Energy Institute

In the entire dataset of the sample, the annual average and median of system availability factors stand at 88% (SD = 13%) and 92%, respectively (Figure 41). This reveals no significant deviation from data released by the government of Japan, as the Study Group for Enhancing Competitiveness of Wind Power Generation (2016) reported that the average availability factor was 87%.

Uchida et al. (2008) aggregated system availability factors among more than 250 wind farms around the world and found the average availability factor stood at 96.4%, and that 50% of them achieved a factor of 97.5% or more. The data were collected more than eight years ago, but supposing that wind power plants around the world generally operate at an availability rate of 96% or 97%, the 88% average in Japan is drastically lower. The median for Japan stands at 92%, again lower than that for the world (97.5%) by five to six percentage points.

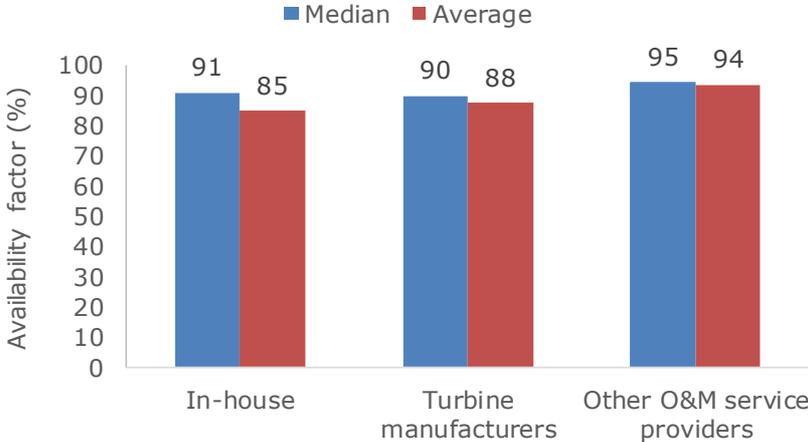
In comparison to wind power plants starting operation before the introduction of the FiT (July 2012), those starting operation after that have achieved a significant improvement in availability factor, at 94% on average. Among them, the median has also risen slightly, to 93%. Through their analysis, Uchida et al. (2008) found that at the start, wind power plants operate at a lower availability factor, before making improvements over time, stating, "In the quarter just after power plants start operation, they operate at an availability factor of 93%, then the figure rise to 96% in two years. Within another 10 years, the availability factor stabilizes between 97% and 98%." (Uchida et al., 2008)

<sup>15</sup> According to Uchida et al. (2008), "the system availability factor of a wind power generator is the number of hours that it being made operational and ready for operation during a certain period divided by hours of the entire period." For the purpose of measuring economic viability, they insist that the availability factor be calculated over a wind farm, not for individual generators, and that almost all the hours of suspension be treated as factors that reduce availability in the calculation, regardless of what caused the suspension.

Given the findings, older power plants that came into operation before the introduction of the FiT, having solved early troubles to establish stability of operation, should be running at a higher availability factor than those getting started later. In fact, however, the data collected for this survey give the opposite result. The reason(s) behind this contradiction remains to be examined further.

**Maintenance service providers and the actual availability factor**

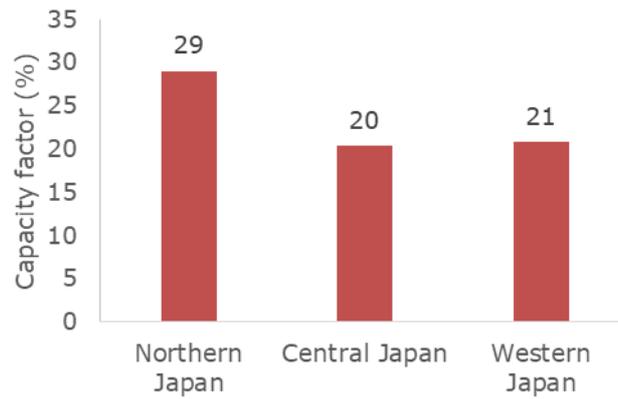
As mentioned in the previous chapter, there are three ways to cope with maintenance: by the power producers themselves, by turbine manufacturers, and by O&M service providers. Whether the actual availability factor differs between these three types of managing maintenance ways offers precious information. Figure 42 suggests the possibility that the availability factor, both in the average and median, is higher among plants operated and maintained by O&M service providers. Given that, as shown before in Figure 40, O&M service providers successfully keep repair costs lower, a smaller number of machine failures and other troubles would be a probable contributor to better availability factor. The limited size of the sample, however, leaves open, for more careful examination, the question of whether the trends observed here in terms of the actual availability factor between different O&M service providers reflects that of all around Japan.



**Figure 42 Actual availability factors by type of O&M service providers**  
 Source: Renewable Energy Institute

**Capacity factor**

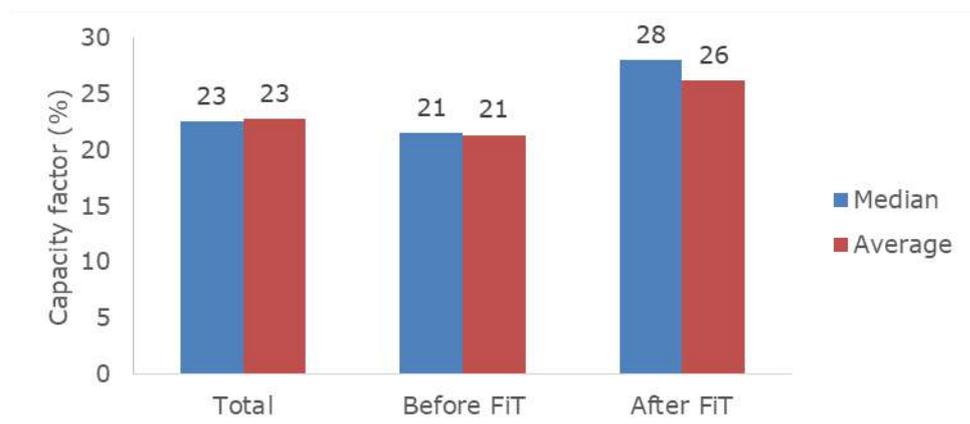
The capacity factor of a wind power plant represents its efficiency based on the actual amount of electricity generated, one of the critical indicators used to evaluate economic profitability of wind power facilities. In general, wind power plants built in a place with better wind resource quality are able to produce more electricity than others, naturally delivering a higher capacity factor. That is also the case when comparing countries. Countries that can exploit good wind resource quality in a larger part of their land can see a higher capacity factor among the wind farms they develop. Here, locational factors also play a significant role. The same applies in individual countries, as areas have good wind resource quality while others do not. Based on the data collected, Figure 43, dividing Japan into three broad regions, shows average capacity factors of wind power plants depending on locations. It is found that the average capacity factor is significantly higher in Northern Japan, demonstrating better wind resource quality there.



**Figure 43 Average capacity factor by region**

Source: Renewable Energy Institute

On a nationwide basis, the data collected indicate a capacity factor of 23%, both in average and median (Figure 44). It is much higher than the average capacity factor reported on a nationwide basis by the ANRE (2016) in its data, around 19%. However, the two figures should not be compared directly, as the ANRE's data include those of power plants constructed before 2005.



**Figure 44 Capacity factor (average & median)**

Source: Renewable Energy Institute

Wind power plants are divided into two groups based on the periods in which they came into operation, before the introduction of FiT (January 2005–June 2012) and after that (July 2012 and later). The two groups show significant differences in capacity factor. In the latter group, the capacity factor, observed in the average, is much larger, by five percentage points. The higher capacity factor may be attributable to two elements. One is the locational factor. Among the sample of data collected, since the introduction of the FiT, more facilities have been constructed in Northern Japan, a region with better wind resource quality, which seems to have resulted in a higher capacity factor (Figure 8). The other is the industrial factor. Since the introduction of the FiT, the capacity factor has also been rising at facilities located in other areas than Northern Japan. That might be attributable to some sampling bias. However, that may reflect a higher efficiency achieved by the combination of better availability factor (Figure 41), as well as higher hub height and larger swept area (Figure 17).

## Conclusions and themes for further research

This final chapter reviews the findings of this report and offers some suggestions for cost reduction, before identifying research themes that remain to be studied.

### Review of the current state of wind power costs in Japan

When examining wind power costs, the focus should be placed on the costs needed to produce 1 kWh of electricity, or the LCOE. Table 9 below summarizes the findings of the analyses performed so far in this report, showing the direction of changes in factors that have impact generation costs of wind power (investment and O&M costs, and actual amount of electricity produced) in recent years (2014–2016).

**Table 9 Influences on wind power costs in recent years**

		International factor	Domestic factor			Unknown
			Locational factor	Institutional factor	Industrial factor	
Investment costs	Turbine costs	↓	-	↓	↓	-
	Civil engineering costs	-	↓	-	(↑)	↑
	Electrical work and connection costs	-	-	-	(↑)	↑
O&M costs	General management costs	-	-	↓	↑	↑
Electricity generated	Capacity factor	-	↑	-	↑	-

Note: Arrows, "↑" and "↓," imply possible impacts of the factor that may push costs up or down, respectively.

The first row indicates the trend of turbine costs. After the revision of the Building Standards Act in 2007, which notably introduced tighter earthquake-resistance regulations developers in Japan had to pay prices significantly higher than global prices when concluding a procurement contract for wind turbines (around 2008), an institutional factor. The FiT guarantees long-term purchase contracts with fixed preferential prices, helping to increase the return on investment in wind power and to expand the market. Before its introduction, under the renewable portfolio standard (RPS) system, terms and conditions for the purchase of wind power electricity were determined by electricity utilities or on a negotiation basis in individual contracts.

Some changes are also observed in civil engineering costs as more wind power plants are located in Northern Japan and lowlands (Figure 24). Civil engineering costs tend to be lower in lowlands than in mountainous areas (Figure 23). These locational conditions seem to have appeared under the influence of certain institutional factors. Before, availability of grid connection for wind power plants was controlled under the concept of limited connection capacity, as limits to grid connection capacities were allotted by vertically integrated electricity utilities, except Tokyo, Kansai, and Chubu Electric Power Companies. No access to the grid was available for wind farms unless bids were invited. Even under such restrictions, the quota for the service area of Tohoku Electric Power was increased to a fairly large size from around FY2008 to FY2011.<sup>16</sup> With the introduction of the FiT, developers are now allowed to apply for grid connection at any time, instead of waiting for any invitation from vertically integrated electricity utilities.

<sup>16</sup> For instance, before FY2008, Tohoku Electric Power had set an annual quota at dozens of MW or issued no invitation at all. The company raised the limit to 160 MW in FY2008, 270 MW in FY2010, and 480 MW in FY2011.

Although these changes should have pushed down costs, actual costs rapidly increased, for reasons which are not always possible to identify. That is also the case for electrical work and connection costs. Actually, at least in parts of the Tohoku region lying along the Pacific coast, some local factors, such as the soaring labor cost and material prices for civil engineering due to the reconstruction work demand after the Great East Japan Earthquake, might offer an explanation. However, on a nationwide basis, they did not increase by more than a few percentage points.

In this regard, some experts and business operators stated that lack of the developers' expertise and financing abilities may be some factors. Most of the developers (especially among such developers other than the largest ones as included in the data collected) have yet to have much experience of development, relying heavily on large EPC contractors in overall management and/or execution of construction work. Under such conditions, power producers and EPC contractors are not on an equal footing. Another factor that may contribute to the increased costs lies in a probable sellers' market for the construction and electrical equipment industries with the recent demand for reconstruction work after the Great Earthquake, and increased demand for electrical work after the introduction of the FiT and the accident at the Fukushima Daiichi nuclear power plant in March 2011.

Some financial institutions stated that considering their business risk, they face difficulty in structuring any financing arrangements for developers other than the largest ones unless they partner with trustworthy, large EPC contractors. To put it the other way around, EPC contractors assume diverse risks in development, and pass them on to the prices, which consequently push up the overall costs.

Some experts say this is rarely the case now for solar PV, as developers have already gotten much experience in the sector. With only small capacities installed so far, the wind power sector has yet to reach market and industrial maturity. Such lack of experience may be among the factors that hinder cost reduction. Whether these arguments may be correct deserve further examination.

Among the O&M costs, regular maintenance & administration costs were found correlated with annual installed capacity. Some experts have stated that maintenance is easier when more of the installed turbines are selected from similar models, a fact that may have something to do with the observed correlation. The relationship, if it really exists, may explain lower regular maintenance & administration costs in Germany, where large wind power capacities, several gigawatts, are installed annually. In terms of development of maintenance services, relationships with cumulative installed capacity should be examined. However, that should be a theme for a separate study, as it requires international comparisons.

At the same time, it has been found that facilities that started operation after the introduction of the FiT have regular maintenance & administration costs which are double the ones of the facilities that started before the FiT. In this respect, some experts and maintenance service providers stated that with the FiT, power producers can now afford to spend more for operation management. That may produce some positive effects as well, such as a larger availability factor, that should contribute to increases in the amount of electricity generated.

#### Study on possible cost reductions for wind power

With its limited size of data and availability of information, this research has yet to fully analyze all the cost items to explain what specifically causes increases in each of them and why wind power remains costlier than in other countries. Keeping such shortage of information in mind, this section examines what action could be led to reduce wind power costs.

##### (1) Maintaining an improved business and market environments

Since the introduction of FiT, business environments for wind power in Japan have been gradually improving with favorable purchase prices and better access to the grid network. That has encouraged foreign turbine manufacturers to enter the Japanese market again, with a gradual recovery of installed capacity. Such changes in business conditions seem to have promoted competition between

manufacturers, with consequent reductions of turbine costs, an item that accounts for the largest portion in investment costs. In this sense, maintaining the attractiveness of Japan for turbine manufacturers as a wind power market is key to cost reduction.

(2) Growth of the entire market as a possible solution to cost reduction

This report, having analyzed past and current data of Japan, has yet to fully examine any impact of the small size of its market on costs. Such examination would require international comparisons. An analysis for this research has found a strong negative correlation between regular maintenance & administration costs and annual installed capacity. The cost item also seems to have the number of turbines administered by individual operators, not the size of power plants, as a significant factor. At least, this suggests that growth of the entire market would be a critical factor, given its relationship with efficiency of supply chains for goods and services, and the level of expertise of the sector as a whole.

(3) Relaxation of restrictions on development in promising regions and sites

Economic feasibility of wind power also depends largely on locational conditions. For instance, Northern Japan offers better wind resource quality, which helps achieve a higher capacity factor. In turn, a larger capacity factor naturally pushes down LCOE of electricity produced. However, Hokkaido and Tohoku Electric Power Companies, responsible for grid operation in this area, have rigorously controlled and restricted access of wind power producers to the grid. With the introduction of the FiT, which transferred the grid connection system from invitation basis into application basis, and the "Pilot Program for Development of Grid Networks for Wind Power Generation," implemented by the Ministry of Economy, Trade and Industry, many wind power projects have concentrated in Northern Japan. However, existing transmission lines, including regional interconnection and intra-regional grid, are not used or operated optimally. As a result, wind power producers may be charged heavily for expansion of a grid network and/or they may be subject to curtailment. These remaining restrictions on the development in regions of great economic rationality should be removed through vigorous efforts.

Any relaxation of restrictions on farmland use may also help reduce wind power costs. As mentioned before, civil engineering costs tend to be smaller for power plants constructed in lowlands than those in mountains. In addition, plants located in mountains often face difficulties in transportation, hindering adoption of larger turbines. In this respect, construction of power plants in lowlands and tablelands, may help reduce wind power costs.

The question here is whether any potential location for wind power plants can be found in lowlands and/or tablelands. A great promise would lie in farmland. Farmland may offer suitable sites for reducing costs for transportation, civil engineering, and grid connection, among others, as it probably has sufficient infrastructure, including access roads and transmission lines, developed until now. Wind power plants need smaller foundations (in square meters) on which they are built, giving less influence on farmland they stand on and farm work carried out there. That means wind power can coexist with farming. Indeed, wind power plants have been constructed in farmland around Japan, and turbines are also turning over farm fields as a common part of landscape overseas. However, Japan's farmland-related legislation imposes tight controls, in principle prohibiting construction of wind power plants on highly productive farmland, such as Agricultural Zone, and Class-1 farmland. Behind that lie, among others, tougher restrictions laid down on development in 2009 by the Ministry of Agriculture, Forestry and Fisheries, mainly to preserve Highly Productive Agricultural Land. Instead of tightening regulations in a uniform manner with other types of development, wind power should rather be explored extensively, helping farmers acquire a stable source of additional income to pursue a way of coexistence with farming. Lifting and/or relaxing such regulations on wind power would contribute to reducing wind power costs.<sup>17</sup>

---

<sup>17</sup> For more details on regulations of use of farmland, see a report presented by Renewable Energy Institute, "Study of Land Use Regulations and Environmental Assessment for Greater Deployment of Wind Power Generation."

#### (4) Guarantee of transparency of regulation and accelerated procedures

During interviews some developers in Europe pointed out great importance of "No surprise," or transparency of regulation. What they consider crucial is that laws and regulations must make clear what type of turbines they are allowed to build where, and under what conditions. Otherwise, power producers could not evaluate their risk of failing to obtain a license and/or permission before starting development, and would eventually fail in development more frequently, and/or see increased cost for planning & development and financing. In addition, procedures for permits and licenses must be completed faster. The longer development takes, the costlier it will be, and the less efficient investments will be.

In this respect, during interviews some experts and developers pointed out some challenges they encounter during the process of the structure safety inspection. Under the Building Standards Act, revised in 2007, developers are required to receive authorization for strength of support structures used for wind power when they are taller than 60 meters (approval of the Minister of Land, Infrastructure, Transport and Tourism until FY2013, or success in the inspection by Regional Industrial Safety and Inspection Departments of the METI from FY2014). From FY2014, the Regional Industrial Safety and Inspection Departments are required to complete an inspection of a standard turbine within 30 days.<sup>18</sup> In fact, however, the Electric Power Safety Division of the METI says that the Regional Departments gave up determination for almost half of the applications, referring them to an expert council composed of academics.

Some experts and power producers said the expert council abruptly adds new inspection items in the midst of inspection and/or leaves some of the inspection criteria poorly defined, a problem which frustrates manufacturers and EPC contractors. Naturally, these uncertainties and risks all help push up costs. Indeed, in Japan, a country quite susceptible to earthquakes and typhoons, keeping safety of wind power plants at a certain level is critical. However, making safety inspection more transparent while carrying out procedures faster to save time and labor needed for, and mitigate risks lying in, inspections would not compromise safety, and rather help introduce more cost-efficient facilities and equipment for wind power.

#### (5) Encouraging developers to develop expertise

Figure 14 has shown that turbines tend to cost more in Japan when procured through EPC contractors. As mentioned in the previous section, construction costs, such as costs for civil engineering and electrical work, have recently risen to so high a level that cannot be explained by labor costs and/or material prices alone. Some state that such rapid increases may be an influence of relationships between developers and EPC contractors including design ability and financing.

Experts stated that what is crucial to bring changes is to adopt the separate-contract system, which should include competitive bidding for designing and construction work. That requires first, however, that developers acquire relevant knowledge, experience, and competence. In Europe, developers have been engaged in a great number of development projects, gone through extensive learning experience and worked hard to maximize economic viabilities and reduce costs. They have obtained know-how for "designing right specifications, integrating all tasks for optimization, and managing the processes to prevent any delay. They also know how to encourage contractors to compete in each process and maximize the profitability." Their know-how has not been acquired in a day. Rather, it is an accumulation of lessons they have learned and improvements they have made through their rich experience of development projects, or "improving by doing."

In Japan, growth of the wind power market has long been depressed, and developers may have been offered only limited opportunities of improving by doing through experience. It is said that wind power projects in Japan take ten years before commissioning. That increases costs for planning & development and construction work, and what is worse, would deprive developers of opportunities of

---

<sup>18</sup> Working Group on Strength of Facilities for Wind Power Generation of the Subcommittee on Electric Power Safety, Industrial Safety Committee, Industrial Structure Council (2013)

improving by doing. The government of Japan is also expected to provide all possible support for reducing time that individual development projects need before completion.

### Themes for further research

Lastly, this section presents themes for further research. First, more data should be collected. As has been stated so far, data collected for this research show no significant divergence from the overall trends of the population while, for power plants starting operation between 2014 and 2016, data were collected mainly from smaller plants, which may not fully represent trends of the population.

The limited size of the sample also served as a restriction on comparative analyses under the same conditions, forcing samples to be roughly grouped when compared, and reducing the accuracy of the analyses. Further effort must be exerted to collect a larger number of data.

Finally, this research focuses on explaining the current cost structure, putting aside quantitative assessment of possible solutions for reducing costs. Specifically, given the small size of the Japanese market itself, what effect any growth of the market may result in with regard to wind power cost reduction remains to be examined. While collecting more data and analyzing the current state of the markets around the world, the author will work to demonstrate in a quantitative manner how much of the generation cost could be reduced.

## References

### Japanese literature

- The Power Generation Cost Verification Working Group (2015), 'Report to the Subcommittee on Long-term Energy Supply-demand Outlook on Long-term Forecast of Energy Supply and Demand,' The Power Generation Cost Verification Working Group of the Advisory Committee for Natural Resources and Energy (発電コストワーキンググループ (2015)「長期エネルギー需給見通し小委員会に対する発電コスト等の検証に関する報告」総合資源エネルギー調査会発電コスト検証ワーキンググループ)
- Tsutomu HAYASHI (2008), 'On Revisions of the Laws Related to Wind Power Generation Facilities, etc.,' "Wind Energy," vol. 32 (3) pp. 77-78. (林農 (2008)「風力発電設備にかかわる法改正など」『風力エネルギー』vol. 32 (3) pp.77-78.)
- The Study Group for Enhancing Competitiveness of Wind Power Generation (2016), 'Report of the Study Group for Enhancing Competitiveness of Wind Power Generation' (風力発電競争力強化研究会(2016)「風力発電競争力強化研究会報告書」)
- The Ministry of the Environment (2016), 'FY2015 Report on Preparation of Basic Information for Zoning Concerning Renewable Energy' (環境省 (2016)「平成 27 年度 再生可能エネルギーに関するゾーニング基礎情報整備報告書」)
- Japan Wind Power Association, General Incorporated Association (JWPA) (2017), 'Installed Capacities of Wind Power Generation as of December 31, 2016, and Estimates of Installed Capacities as of March 31, 2017' (JWPA: 一般社団法人 日本風力発電協会 (2017)「2016 年末の風力発電導入量と、2017 年 3 月末の推定導入量」)
- Emi MIZUNO (2013), 'Cost of On-shore Wind Power Generation in Japan: Current State and Analysis,' Discussion Paper of Renewable Energy Institute (水野瑛己 (2013)「日本の陸上風力発電コストの現状と分析」自然エネルギー財団ディスカッションペーパー)
- New Energy and Industrial Technology Development Organization (NEDO) (2008), 'Guidebook for Development of Wind Power Generation' (NEDO: 独立行政法人 新エネルギー・産業技術総合開発機構 (2008)「風力発電導入ガイドブック」)
- New Energy and Industrial Technology Development Organization (NEDO) (2016), 'Wind Power Generation Facilities in Japan: Data as of March 2016' (NEDO: 国立研究開発法人 新エネルギー・産業技術総合開発機構 (2016)「日本における風力発電・設備導入実績(2016 年 3 月末現在)」)
- Working Group on Strength of Facilities for Wind Power Generation of the Subcommittee on Electric Power Safety, Industrial Safety Committee, Industrial Structure Council (2013), 'Report of the Working Group on Strength of Facilities for Wind Power Generation of the Subcommittee on Electric Power Safety, Industrial Safety Committee, Industrial Structure Council' (産業構造審議会保安分科会電力安全小委員会風力発電設備構造強度ワーキンググループ (2013)「産業構造審議会保安分科会電力安全小委員会風力発電設備構造強度ワーキンググループ 報告書」)
- The Agency for Natural Resources and Energy (2016), 'Trends of Costs by Type of Power Source (Solar PV & Wind),' 25th meeting of the Procurement Price Calculation Committee (資源エネルギー庁 (2016)「電源種別(太陽光・風力)のコスト動向等について」, 第 25 回調達価格等算定委員会)
- Yukinobu UCHIDA, Harman, K., Walker, R., and M. Wilkinson (2008), 'Trends of the Availability Factor among Wind Farms: Findings from Surveys of Wind Farms in Service in Europe, the United States, and Asia,' "Symposium on Deployment of Wind Energy," Vol. 30, pp. 144-147 (内田行宣, Harman, K., Walker, R., and M. Wilkinson, (2008)「ウインドファーム稼働率の傾向について—欧州・米国・アジアで稼働中のウインドファーム調査結果—」『風力エネルギー利用シンポジウム』Vol. 30, pp. 144-147.)

### English literature

- BNEF: Bloomberg New Energy Finance (2015) "The future cost of onshore wind – an accelerating rate of progress"
- BNEF: Bloomberg New Energy Finance (2016a) "H2 2016 Global LCOE Outlook"

- BNEF: Bloomberg New Energy Finance (2016b) "H2 2016 EMEA LCOE Outlook"
- BNEF: Bloomberg New Energy Finance (2016c) "H2 2016 AMER LCOE Outlook"
- BNEF: Bloomberg New Energy Finance (2016d) "H2 2016 APAC LCOE Outlook"
- BNEF: Bloomberg New Energy Finance (2017) "H2 2016 Wind Turbine Price Index"
- Bolinger M. and R. Wiser (2011) Understanding Trends in Wind Turbine Prices Over the Past Decade, Lawrence Berkeley National Laboratory, Berkeley, CA.
- Gonzalez, J. S., and R. L. Arantegui, (2016) "Technological evolution of onshore wind turbines – a market-based analysis," *Wind Energy*, Vol. 19, pp. 2171-2187.
- Lüers, S., Wallasch A.-K., and I. K. Rehfeldt, (2015) Kostensituation der Windenergie an Land in Deutschland, DEUTSCHE WINDGUARD.
- IEA Wind (2006) IEA Wind Energy Annual Report 2006.
- IEA Wind (2008) IEA Wind Energy Annual Report 2007.
- IEA Wind Task 26 (2015) Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the European Union, and the United States: 2007-2012, National Renewable Energy Laboratory.
- IRENA: International Renewable Energy Agency (2015) Renewable Power Generation Costs in 2014. IRENA. Abu Dhabi.
- Leipziger Institute für Energie GmbH (2014) Vorbereitung und Begleitung der Erstellung des Erfahrungsberichts 2014 gem. § 65 EEG im Auftrag des Bundesministeriums für Wirtschaft und Energie Vorhaben IIe Stromerzeugung aus Windenergie - Wissenschaftlicher Bericht.
- Leipziger Institute für Energie GmbH (2015) Marktanalyse – Windenergie an Land, Hamburg.
- Wiser R. and M. Bolinger (2016) 2015 Wind Technologies Market Report, U.S. Department of Energy.

**Disclaimer:** This report has been produced in collaboration with a number of organizations and individuals. However, the entire responsibility for any statement and opinion contained here falls solely on Renewable Energy Institute, and on no other organization or individual. Although the information given in this report is the best available to the author at the time, Renewable Energy Institute cannot be held liable for its accuracy and correctness.

## **Analysis of Wind Power Costs in Japan**

January 2018

(Japanese original was published in June 2017)

### **Renewable Energy Institute**

8F DLX Building, 1-13-1 Nishi-Shimbashi, Minato-ku, Tokyo 105-0003  
Phone: +81-3-6866-1020

[info@renewable-ei.org](mailto:info@renewable-ei.org)

<https://www.renewable-ei.org/en/>