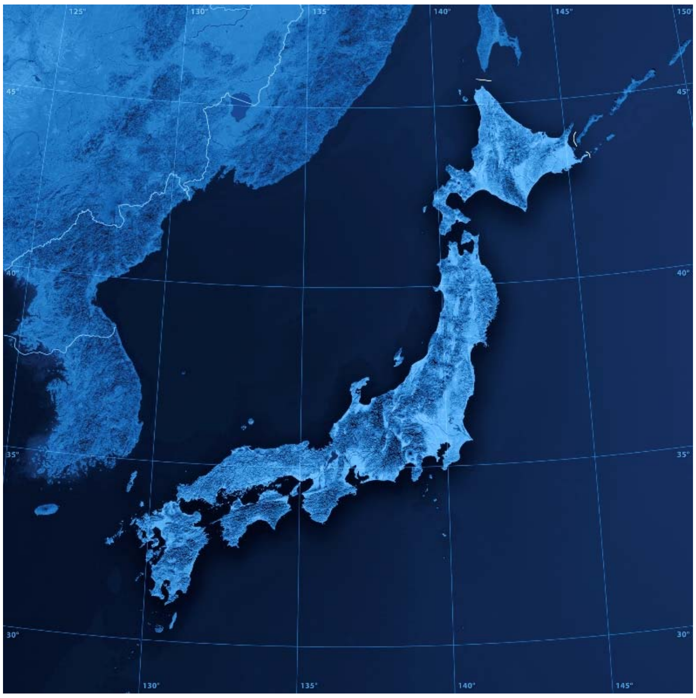
CARBON TRUST

Appraisal of the Offshore Wind Industry in Japan



Working with:

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Executive Summary

Contextual factors relating to the energy market in Japan are leading to a greater emphasis on offshore wind: (1) recent events means that the historic focus on nuclear energy to meet domestic demand has now shifted to other renewable energies; (2) the economic realities of the high cost of imported gas, which has been necessary since 2011 to bridge the gap left by the closure of nuclear plants, accelerates the need to identify alternatives; and (3) the onshore wind sector is facing geographical constraints and social issues, such as visual impact and low frequency noise, meaning its contribution to the renewables mix is expected to peak shortly after 2030. Offshore wind is a major benefactor of these factors, with new policy that sets ambitious targets for offshore wind to 2050 of 37 GW.

Grid

There are fundamental challenges in the grid infrastructure that makes the development of offshore wind difficult. The difference in electricity frequency between east and west means that transmission of electricity requires converters, which are few, thus creating challenges in a world of higher intermittent generation, such as from offshore wind. However, the Basic Policy on Electricity Reform that seeks to abolish the regional utility monopolies may help to address these challenges by enabling freer movement of electricity across regions. This is critical as the source of offshore wind is often in regions of low demand, such as Hokkaido, Tohoku, and Kyushu. So, creating the right infrastructure to facilitate transmission of this supply to urbanised areas, such as Tokyo, is paramount. Utility unbundling is a key step to achieving this.

Deployment Costs

The costs of delivering offshore wind are high globally, and particularly so in Japan, where high base costs and a lack of suitable infrastructure and offshore experience add to the challenge. Hence there is a need for a sensible incentive system to encourage investment from the private sector through Feed-in-Tariff (FIT) mechanisms, as well as providing funding to test novel innovations that can deliver significant cost reductions. Japan is home to some of the most generous renewable FITs in the world, and the recent announcement of a bespoke FIT for offshore wind of 36 JPY/kWh should encourage further private sector engagement in the offshore market. However, it remains to be seen as to whether this will provide sufficient returns to drive the level of investment necessary and kick start large scale offshore development in Japan.

Consenting

As in other markets, the consenting process is too long and the government is keen to reduce this. Furthermore, developers must engage stakeholders, especially with the powerful fishing associations. Poor outcomes emerge when this does not occur, as seen at the Fukushima floating project.

Ports

A key aspect of offshore wind development is adequate supply and quality of ports close to farms. Given the high wind resource in Japan in the north, it is likely that new facilities will be required there to reduce the need for vessels to travel further than necessary to conduct installation and maintenance.

Technical

While onshore wind turbines are dominated by international manufacturers, 86% of offshore wind turbines are manufactured by Japanese companies, with Hitachi and Fuji pre-eminent. Increasingly, local companies are also starting to develop larger models, with Mitsubishi developing a 7MW turbine. This up-sizing is important for the economics of wind farms as they move from demonstration to full scale deployment.

Japan does face very challenging bathymetry, with very deep waters relatively close to its shores. However, it is anticipated that near shore (within 10km and under 20m) will represent the majority of offshore wind farms deployed to 2025, which could be some 2GW. Longer term, Japan will need to install its farms further away and in deeper waters and so must develop greater expertise around floating foundations. Given its pre-eminent position as a global leader in floating foundation R&D, there is every chance that it can attain its 2050 targets for total offshore deployment of 37GW (19 GW of fixed and 18 GW of floating).

Vessel availability is going to be a key challenge facing Japan, given that the early projects have been near shore and not required bespoke vessels. As projects move further out, and indeed when floating structures dominate, the supply chain must develop local expertise in this area. This is starting to happen with the recent purchase by Marubeni and Innovation Network Corporation of Japan of SeaJacks, a British firm that designs and builds bespoke installation vessels for the offshore wind industry.

A key component of the industry is effective operations and maintenance, which given the limited number of deployments means that he industry lacks experience in this area. Access to bespoke vessels to undertake such activity will be critical. Good condition monitoring systems is also key and Hitachi and Mitsubishi have started to incorporate this technology into their offshore turbines.

Conclusions

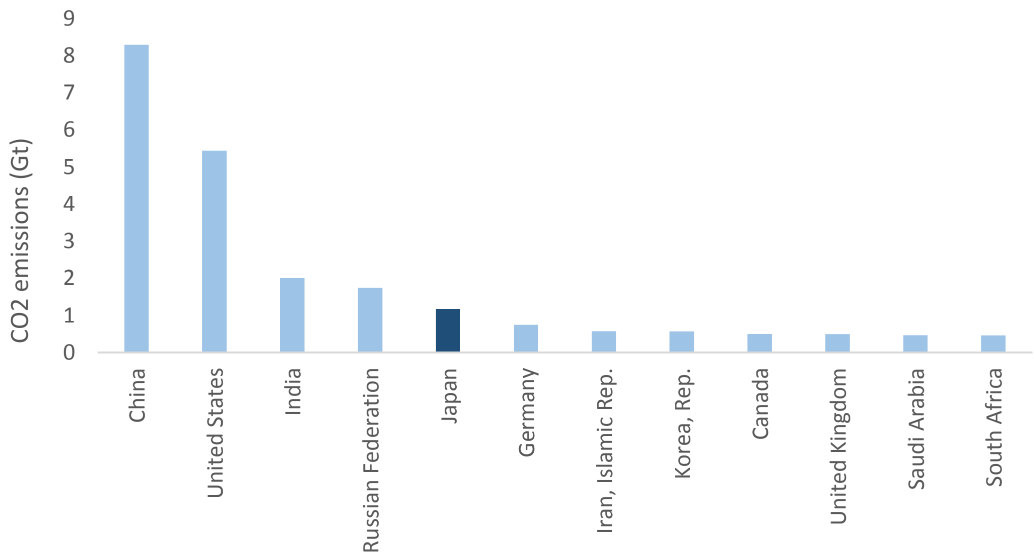
Japan needs offshore wind deployment to happen and has set its timetable. Numerous regulatory, policy and technical issues must be addressed to enable the goal to become reality. Many of the early demonstrations in Japan, especially of floating foundations, have seen many industrial companies partner and work together. These collaborations are a positive sign and could lead to the possibility of setting up collaborative programmes in Japan much like the Carbon Trust's Offshore Wind Accelerator in the UK that includes 9 developers. The next steps of the project will outline these opportunities.

1 Market

1.1 Energy supply and demand in Japan

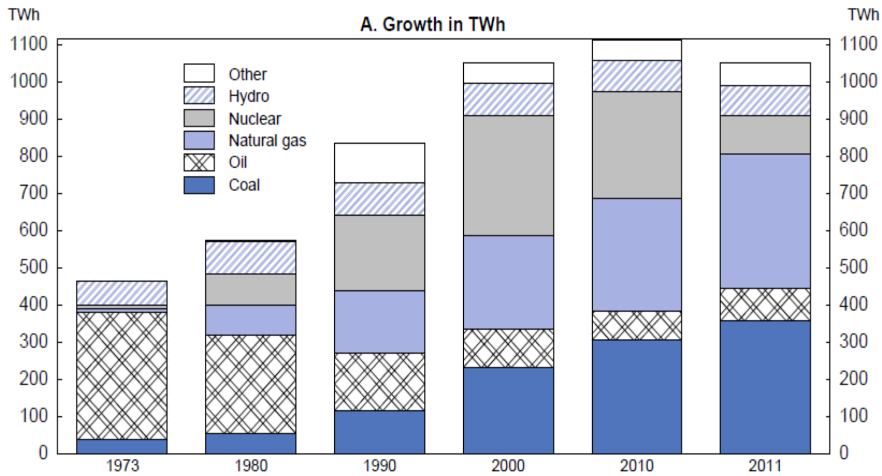
Japan is the world's third largest economy and has the second largest electricity market in the OECD (Jones & Kim, 2013). Even though Japan's economy is very energy efficient compared to other OECD members, it is still one of the world's largest CO_2 emitters, mainly due to its concentration of manufacturing industries. Japan's total CO_2 emissions in 2010 were about 1.2 Gt CO_2, placing it fifth amongst the world's largest emitting countries (The World Bank, 2013). Energy transformation CO_2 emissions are estimated to account for 30% of Japan's total emissions.

Figure 1. Annual CO_2 emissions in 2010 (The World Bank, 2013)



Historically, Japan's electricity energy mix has shifted radically from a very oil intensive country in the early 1970s to a more balanced mix in 2010, with coal, natural gas and nuclear, each representing around 30% of the power generated (Jones & Kim, 2013). Before the Fukushima nuclear disaster, the government's Energy Plan from 2010 was to increase the nuclear share in the electricity mix to about 50% by 2030 (The Japan Times, 2013).

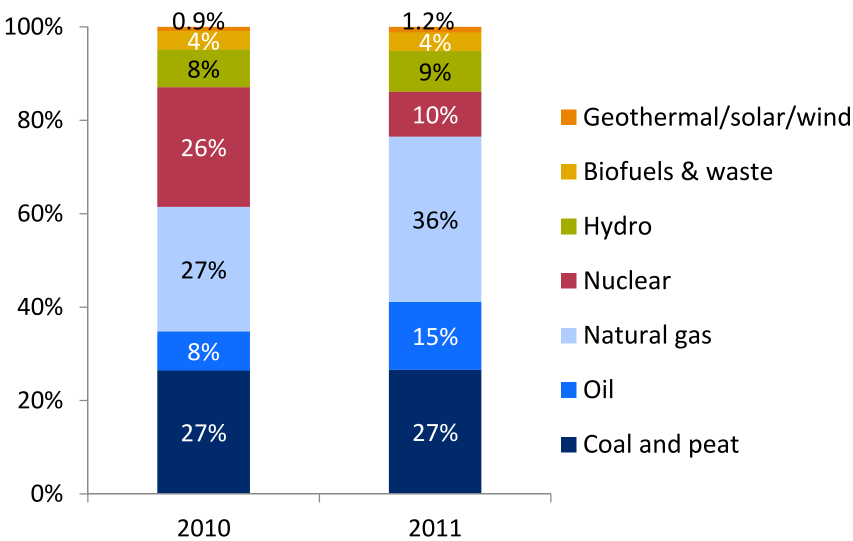
Figure 2. Historical Electric Power Generation in Japan (Jones & Kim, 2013)



In March 2011, the Great East Japan Earthquake hit the coast of Tohoku, triggering a tsunami which had catastrophic human, environmental, and industrial consequences. The Fukushima I Nuclear Power Plant, which was hit by the tsunami, caused severe problems in the Japanese power supply, and consequently all nuclear power plants on the east coast were shut down. Eastern Japan was left in a very vulnerable position with limited capacity to respond to the power demand. Tokyo's main utility power company, TEPCO, saw a dramatic reduction in its capacity to 30% below normal peak demand (Vana Tsimopoulou, 2012).

As seen in Figure 3, in 2011, the year of the Tsunami, average electricity generation shifted to almost 70% fossil fuels and 10% nuclear (International Energy Agency, 2012). Since Japan has limited fossil fuel resources, this drastic change in energy supply meant that they had to increase their liquid natural gas imports, which amounted to approximately $100 million each day (Franco, 2013).

Figure 3. Japan's electricity generation by source (International Energy Agency, 2012)



Japan is the largest liquefied natural gas importer, second largest coal importer, and third largest net oil importer, with a high dependency on imports from the Middle East (U.S. Energy Information Administration, 2013), putting the country in a vulnerable position in regards to energy security.

The increasing level of fossil fuel imports following the Fukushima accident led to a hike in electricity prices. For instance, the regional electric power company TEPCO increased its tariffs for firms by 15% in April 2012 and 8.5% for households later in 2012 (Jones & Kim, 2013). In terms of environmental impacts, Japan's greenhouse gas emissions rose 3.9% in 2012 due to the increased use of fossil fuels after the shutdown of the nuclear power plants (Soble & Cienski, 2013).

According to the Japanese Institute of Energy Economics, primary energy supply is expected to grow back again in 2013 for the first time in three years due to increased economic growth. Thermal power generation will hit a record high of 810 TWh in 2013, but it is expected that oil-fired thermal power will decrease in 2014 due to the restarting of nuclear power plants (Institute of Energy Economics, Japan, 2013). Overall, Japan's electricity demand growth rate is low compared to other OECD countries, estimated to be 0.7% from 2007 through 2018 (The Encyclopedia of Earth, 2013). Total electricity generation is expected to decrease slightly to around 950 TWh in 2030 (Ministry of Economy, Trade and Industry, Japan, 2010).

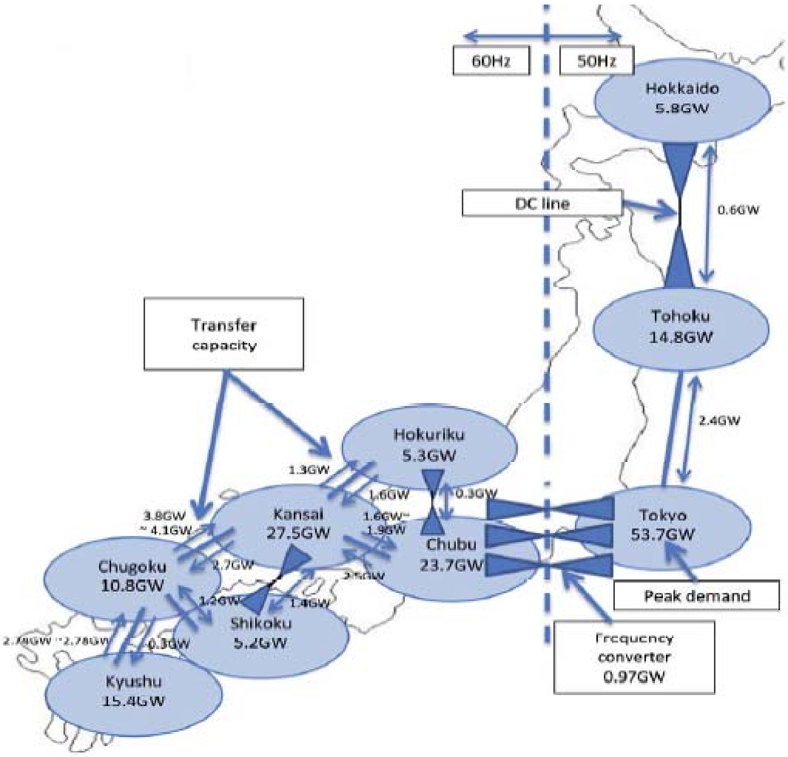
To reduce its dependency on fossil fuels and secure energy supply, Japan is looking to expand its renewable energy use. Indeed, as part of the 2010 New Growth Strategy, the Japanese government announced it expects to create a 50 trillion ¥ market in energy and environmental services and create 1.4 million new jobs in the sector (Ikuta, 2010).

1.2 Electricity market

Japan's electricity system has historically been dominated by nine regional electric power companies. They supply about 88% of Japan's total electricity consumption, while the rest is generated by wholesale electric utilities, such as the Japan Atomic Power Company and J-Power, as well as by private generators (Jones & Kim, 2013). The Japanese Ministry of Economy, Trade and Industry (METI) is in charge of regulating the electricity market.

Japan is divided into two zones, each having a different grid frequency; the eastern part of the country runs at 50 Hz, while the western part runs at 60 Hz. The reason behind this division is that the Tokyo region (east) adopted German generators, while Osaka (west) was using equipment from the United States (The Federation of Electric Power Companies of Japan, 2013). These frequency differences limits the level of electricity transfer. Although there are three frequency converter facilities connecting both regions, their capacity is not sufficient to cover for large power shortages. Figure 4 shows the electricity distribution network across the country.

Figure 4. Electricity transmission network in Japan (Institute of Energy Economics, Japan, 2013)



As seen in Figure 4, Japan's interconnection capacity varies by region. The western side of the country is better interconnected than the eastern part. Indeed, Tokyo's interconnection capacity is only 9% of its total installed generation, while in the northern region of Hokkaido, interconnection is less than 10 (Innovation Norway, 2013). When the Fukushima accident took place, the electric power company TEPCO, which supplies the Tokyo region, was cut off from the western part of the country and the converter facilities were not able to cover for the large electricity shortage which caused rolling blackouts (Jones & Kim, 2013).

In 2012, the Japanese government proposed the Basic Policy on Electricity Reform with the aim of creating a competitive electricity market by reforming the different entities constituting the system, including retail, generation and transmission networks (Jones & Kim, 2013).

1.3 Wind Power in Japan

In 2011, Japan's total renewable energy installed capacity was about 15 GW (excluding large hydropower). As indicated in Figure 5, over 50% of that is from wind and solar photovoltaic installations. Historically, these two sources represented a very low percentage of the renewables mix. However, due to intermittency of wind and solar, actual generation is dominated by small hydro and biomass, which together accounted for about 70% of the total renewable power generated, in 2011. Solar and wind contributed only to 13% and 11%, respectively.

Figure 5. Cumulative capacity of renewable energies in Japan
(Institute for Sustainable Energy Policies, 2013)

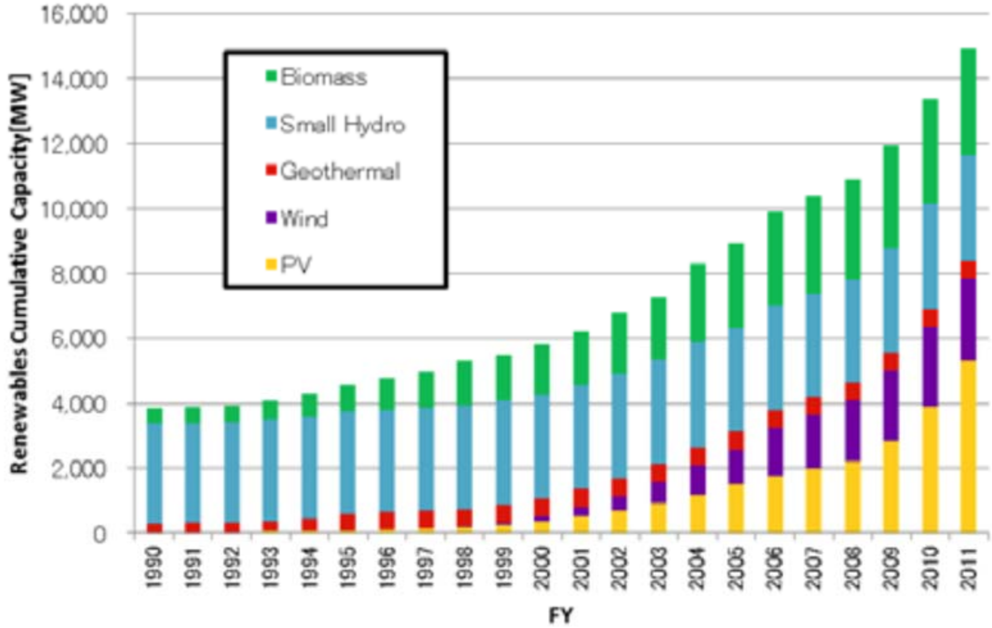
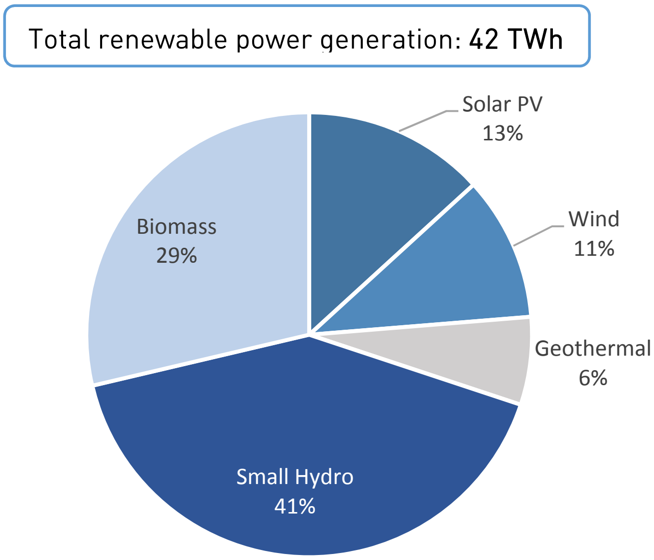
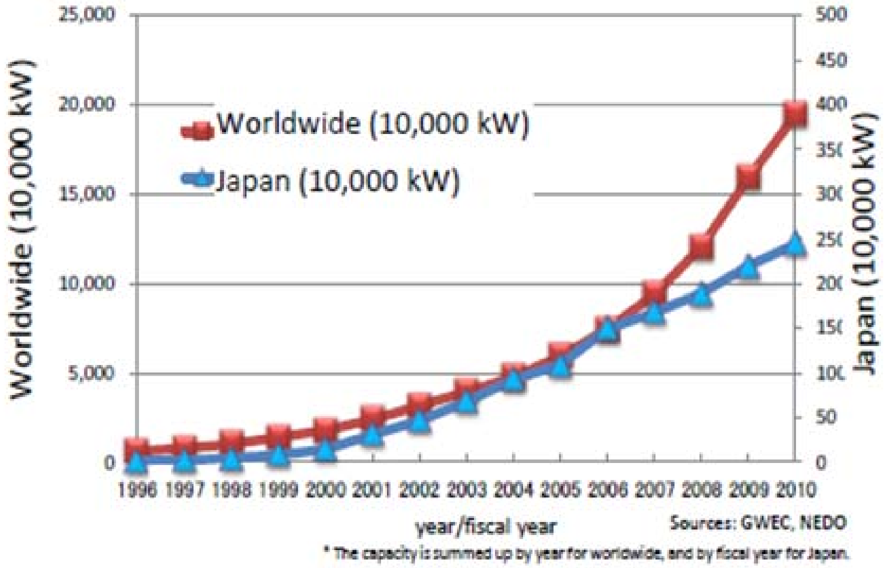


Figure 6. Renewable power generation in Japan in 2011
(Institute for Sustainable Energy Policies, 2013)



As seen in Figure 7, globally, there has been an accelerated growth in wind power generation, but Japan's growth has been stable, amounting to 2.5 GW of installed capacity with 1,832 turbines, ranking 12th worldwide (Arakawa & Ueda, 2012). The relatively slow deployment of wind technology in Japan is due to various technical, institutional, social and economic factors. Japan's typology is complex and the country is exposed to extreme weather conditions such as high wind due to typhoons, turbulence and frequent lightning. Besides the technical issues that need to be overcome, tight regulations and lengthy consenting and planning procedures have hindered private investment. Up until recently, the Japanese government had been mainly focused in strengthening its nuclear power's position than in expanding renewable energy capacity.

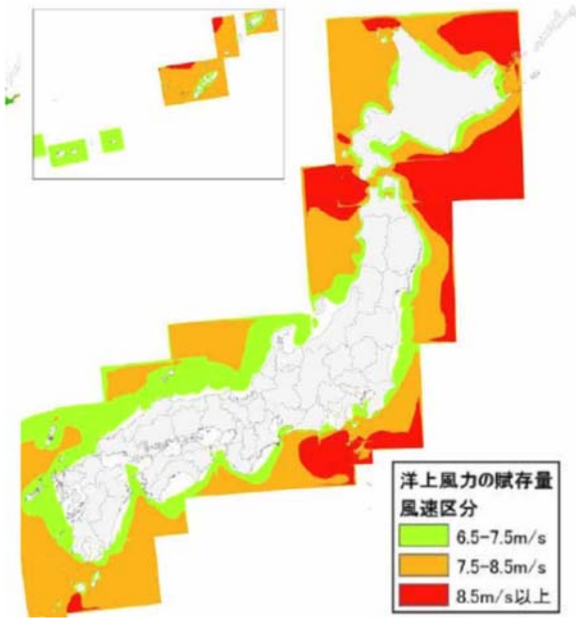
Figure 7. Wind power cumulative installed capacity (Japan Wind Power Association, 2012)



1.4 Japan's offshore wind resource

Having the world's 6th largest sea space, the theoretical offshore wind potential in Japan is estimated to be 1600 GW, with 80% of its wind resources located in deep water (>50m) (Main(e) International Consulting LLC, 2013). According to the Japan Wind Power Association, a realistic offshore wind potential would be around 600 GW, out of which 15% could be exploited using fixed bottom turbines and the remaining using floating technology (Japan Wind Power Association, 2012) (Sasebo Heavy Industries, 2013). As seen in Figure 8, the best wind conditions (shaded in red) are located around the northern island of Hokkaido, Kyushu and Tohoku, far from the highly concentrated electricity demand areas.

Figure 8. Wind speed map in Japan (Ministry of Economy, Trade and Industry, Japan, 2010)



The wind resource potential is estimated using satellite measurement derived ocean wind speeds data sets and ocean bathymetry data (Henderson, Leuts, & Fuji, 2002). In Japan, the Meteorological Agency (JMA) is responsible for the measurement of weather related data and for the monitoring and forecasting of natural phenomena. The JMA operates a mesoscale model for very short range forecasts (Japan Meteorological Agency, 2012) which can be subsequently used to assess offshore wind resource without in-situ measurements.

Several studies have been conducted to investigate the accuracy of wind simulation using mesoscale meteorological models (Oshawa, 2007). The University of Tokyo, in partnership with TEPCO and Kajima Corporation, carried out a study to estimate offshore wind power generation in the east coast of Japan. Wind speed measurements were taken at an existing offshore natural gas platform and compared with estimates using a mesoscale model and Geographic Information Systems (GIS). Results showed that the mesoscale model had a prediction error of 4.1% (Sukegawa, Ishihara, Yamacuchi, & Usami, 2010).

NEDO provides access to wind data conditions, which come from the JMA, as well as a wind resource map indicating yearly average wind speed at heights above 30, 50, and 70 m. NEDO also conducts yearly surveys on wind power facilities in Japan connected to the grid and with a turbine output of 10 kW or more.

1.5 Regional energy supply and demand

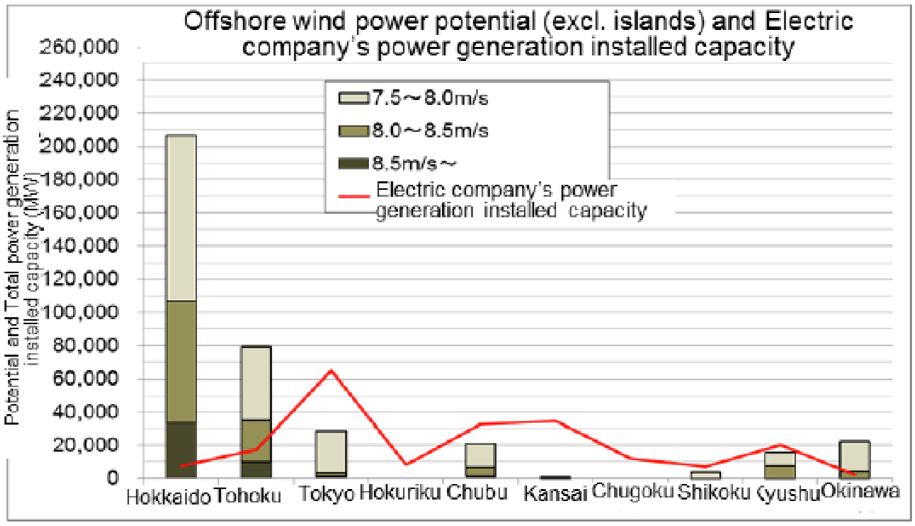
Correlation with wind resource

According to the Ministry of Environment, Japan has an onshore wind power potential of 280 GW and 1600 GW of offshore potential, without considering financial aspects (Arakawa & Ueda, 2012). The total wind power potential is estimated to be eight times the current capacity of its electric power companies (Matsutani, 2013).

The Japan Wind Power Association estimates that 378 GW of offshore wind capacity could be technically possible if one does not consider the capacities of electric power companies. If the current limited grid capacity is taken into consideration, the offshore wind potential would be 96 GW. Figure 9 shows the offshore wind potential and the current installed capacity of the corresponding electric power companies. Offshore wind electricity generation could potentially meet the total power demand in Hokkaido and Tohoku and almost half of Tokyo's demand (Japan Wind Power Association, 2012).

Hokkaido and Tohoku have the highest offshore wind potential, but the electricity demand in these regions is comparably low, with a very limited interconnection capacity.

Figure 9. Offshore wind power potential in Japan (Japan Wind Power Association, 2012)

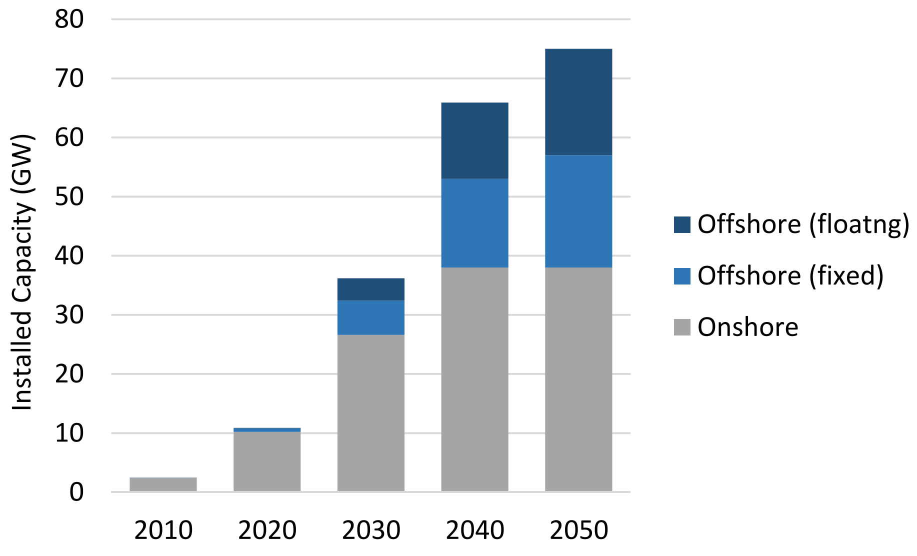


There is an immense challenge to ensure the efficient transfer of power from areas of high wind resource potential to regions of high electricity demand. The Agency of Natural Resources and Energy (ANRE) estimates that the upgrading grid investment costs would be over 310 billion JPY for the regional grid and 1,170 billion JPY for the interregional grid. In 2013, the METI ensured 25 billion JPY to strengthen the Hokkaido grid, and it is expected that extensions in the Tohoku region will start in 2014 (Innovation Norway, 2013).

Wind Power Targets

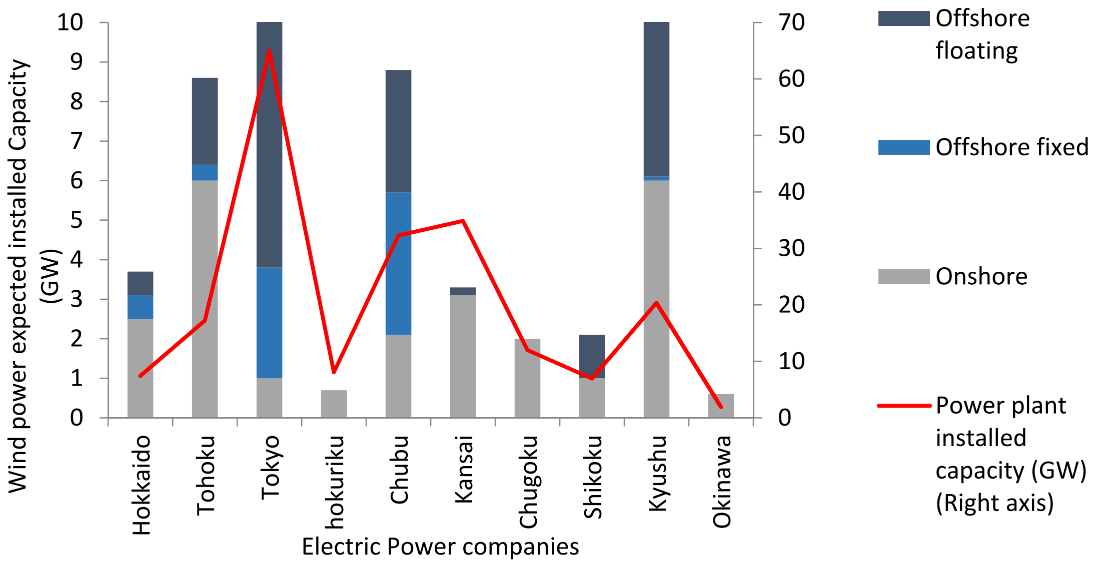
The Japanese government has yet to announce official national targets for offshore wind. However, the Japan Wind Power Association has established a roadmap for wind power deployment, in which it is expected that wind will supply 15% of Japan's electricity by 2050. The wind power installed capacity targets are 10.9 GW by 2020 and 75 GW by 2050. Offshore wind is expected to cover almost half of the total wind capacity by 2050, consisting of 19 GW of installed capacity using fixed turbines and 18 GW by floating turbines (Japanese Wind Power Association, 2014). Official targets could be announced in 2014 as part of the new national energy plan; but, as seen in Figure 10, offshore technology is only expected to be deployed at large scale after 2020.

Figure 10. Goals for wind power installed capacity (Japanese Wind Power Association, 2014)



Most of Japan's potential wind power capacity is located offshore, and out of this, about 80% is concentrated in three regions: Tokyo, Kyushu and Chubu. The leading regions on floating offshore installations will most likely be Tokyo, Kyushu and Chubu, while fixed turbines will mainly be located in Chubu and Tokyo. Although the island of Hokkaido has the largest offshore wind potential, the electricity demand is low in the area; therefore, the installed offshore wind capacity is expected to be less than 2 GW by 2050. In some regions such as Hokkaido, Tohoku, Kyushu, the deployment of wind energy is expected to be about 50% of today's installed electricity capacity, but less than 25% for Chubu and Tokyo (Japan Wind Power Association, 2012).

Figure 11. Expected wind power capacity in Japan in 2050 (Japan Wind Power Association, 2013)

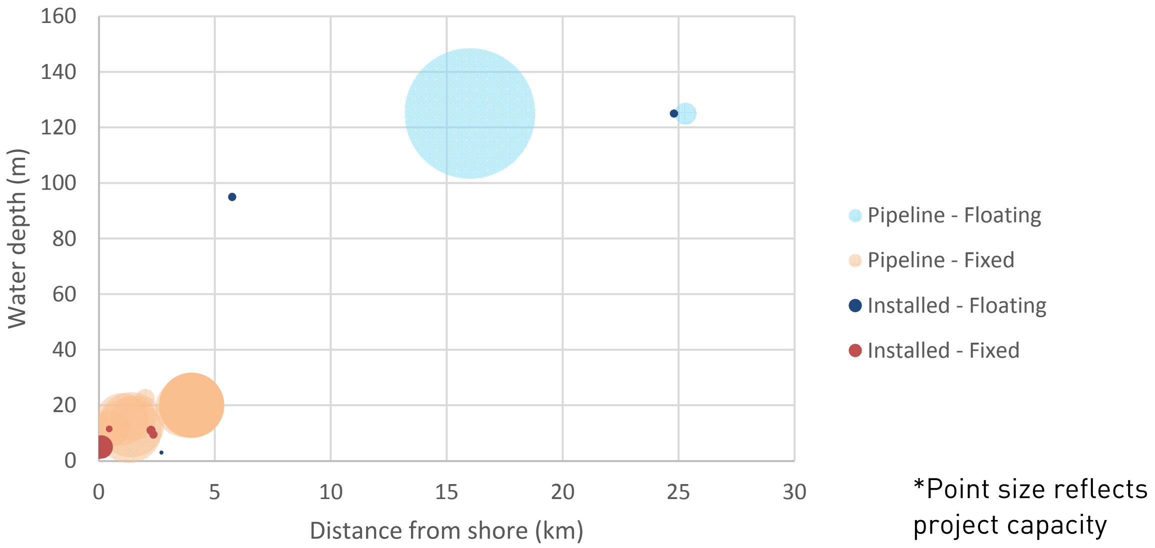


*Carbon Trust analysis, 2013

1.6 Current and Planned Projects

Japan has a total of 49.7MW of offshore wind installed capacity using 28 turbines at 8 locations (4coffshore, 2013). The majority of existing installations are fixed-bottom turbines (45.7 MW of total installed capacity) located very close to shore (<2.5km) in water depths up to 25m. Early demonstration floating turbines (4 MW of total installed capacity) are located further from shore (15-25km) in water depths >100m. The proximity to shore of fixed-bottom projects, and the desire to develop floating technology, are largely due to the bathymetry surrounding Japan's coastline. Water depth increases dramatically, creating challenges for developing offshore wind. While fixed-bottom technology is currently more mature and lower cost, locating turbines close to shore can cause problems with regard to consenting (e.g. visual impact; conflict with other maritime activity) and maximising yield (the strongest wind resource is typically located further from shore).

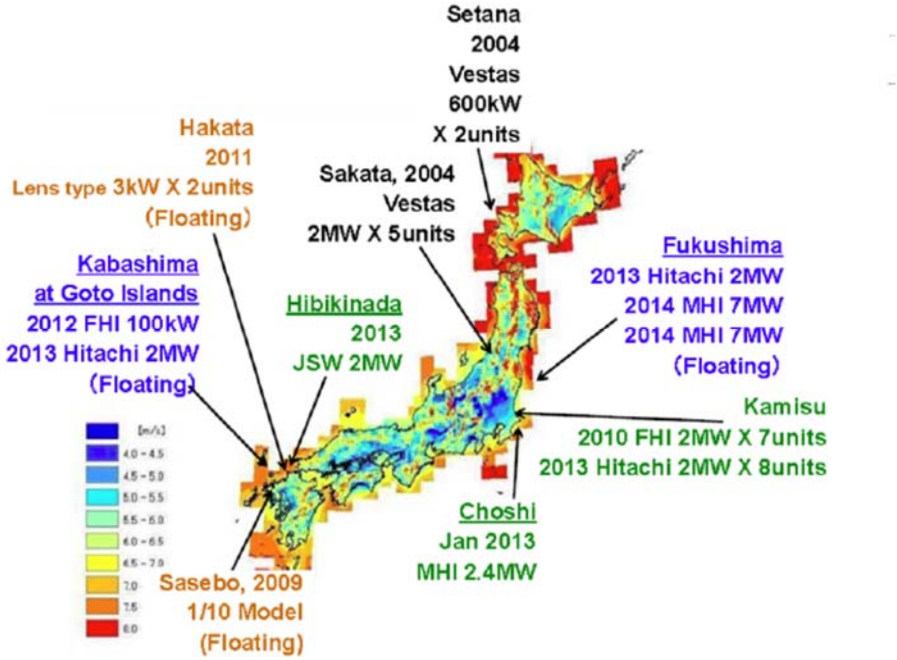
Figure 12. Site location and size of offshore wind projects in Japan



In the near- to medium-term, offshore wind capacity is expected to be developed mostly close to shore with fixed-bottom turbines, but as floating technology matures and reduces in cost, this is expected to dominate offshore wind development over the longer-term beyond 2030. Indeed, Japan is well positioned to lead the global floating offshore wind market, with growth also expected in the United States and Europe over the coming decades.

Although the current installed offshore capacity in Japan is very low relative to countries such as the UK and Denmark, the country has great ambitions to achieve their 37 GW target by 2050. Figure 13 provides an overview of the main offshore wind projects in Japan (Japan Wind Power Association, 2013).

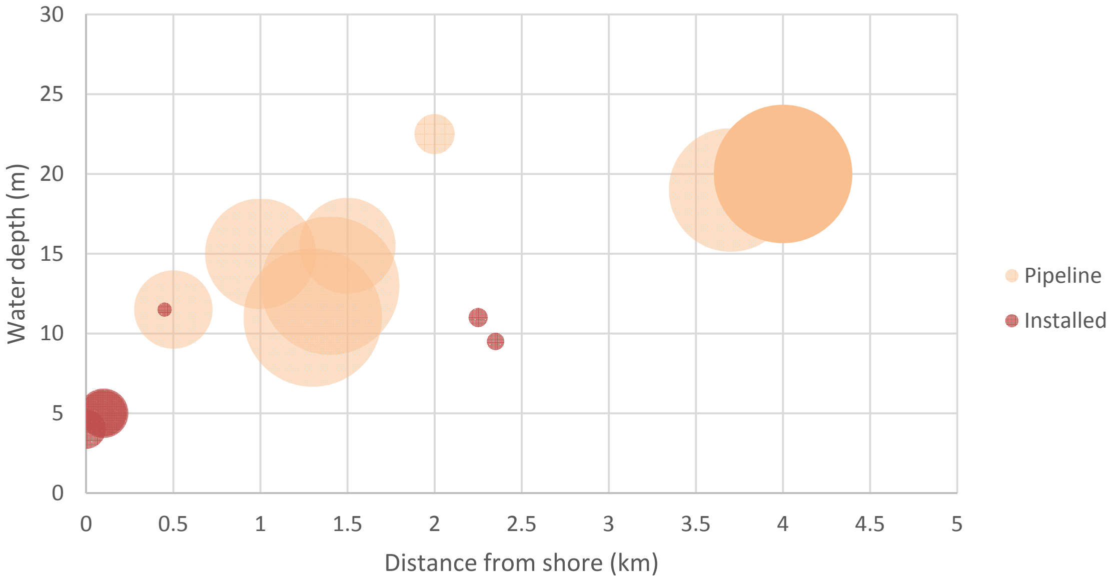
Figure 13. Offshore wind projects in Japan (Japan Wind Power Association, 2013)



Fixed-bottom offshore wind projects

Japan has 45.7 MW installed capacity from fixed-bottom turbines. To date, these have been located very close to shore, within 500m of the coast in 4-5m deep waters. Japan only has two genuinely offshore projects, both single turbine demonstration projects, which have been located just over 2km from shore, in 12-14m water depth. Even projects currently in the pipeline do not push beyond 5km from shore, up to a maximum depth of 20m, beyond which the technology challenges and cost implications for offshore wind power become more acute. Consenting difficulties have also imposed restrictions, with a number of projects being located in port areas, where fishing regulations are less strict.

Figure 14. Site location and size of fixed-bottom wind projects in Japan



*Point size reflects average project capacity

Table 1. Details of fixed-bottom offshore wind projects in Japan (installed and pipeline) (4coffshore, 2013)

Name	Region	Project size (MW)	Turbines size (MW)	Turbine manufacturer	Foundation type	Operational	Status
Sakata Nearshore Offshore Wind Farm	Tohoku	10	2	Vestas	High-rise pile cap	2004	Fully commissioned
Setana Nearshore Demonstration Project	Hokkaido	1.32	0.66	Vestas	High-rise pile cap	2004	Fully commissioned
Kamisu Nearshore Wind Farm - Phase 1	Kanto	14	2	Hitachi/Fuji	Monopile	2010	Fully commissioned
Kamisu Nearshore Wind Farm - Phase 2	Kanto	16	2	Hitachi/Fuji	Monopile	2013	Fully commissioned
Choshi Offshore Demonstration Project	Kanto	2.4	2.4	Mitsubishi	Gravity base	2013	Fully commissioned
Kitakyushu Offshore Demonstration Project	Kyushu	2	2	Japan Steel Works	Gravity base	2013	Fully commissioned
Mermaid Project (Ikeshima) - Phase 1	Kyushu	2	2	Not decided	Suction bucket	2015	Concept/Early Planning
Mermaid Project (Ikeshima) - Phase 2	Kyushu	5	5	Not decided	Suction bucket	2016	Concept/Early Planning
MAEDA - Yasuoka - "Shimonoseki"	Chugoku	60	3/4	Not decided	Not decided	2016-17	Concept/Early Planning
Ibaraki Kashima port - Megasite - North - Wind Power Energy	Kanto	125	5	Not decided	Not decided	2017	Concept/Early Planning
Kamisu - Megasite - South - Marubeni Corporation	Kanto	125	5	Not decided	Not decided	2017	Concept/Early Planning
Aqua Commercialisation Study Group	Tohoku	7.5	2.5	Toshiba	Not decided	2017	Concept/Early Planning
Mutsu-Ogawara Port	Tohoku	80	2.5	Not decided	Not decided	2018	Concept/Early Planning
Ibaraki - Megasite - Phase 2 (Marubeni)	Kanto	125	5	Not decided	Not decided	Unclear	Concept/Early Planning
Kamisu - Megasite - Phase 2 (Wind Power Group)	Kanto	125	5	Not decided	Not decided	Unclear	Concept/Early Planning
Ishikari Bay	Hokkaido	100		Not decided	Not decided	Unclear	Concept/Early Planning
Omaezaki	Chubu	40	4.5	Not decided	Not decided	Unclear	Concept/Early Planning
Akita - "Kingdom of Wind"	Tohoku	10.5	3.5	Not decided	Not decided	Unclear	Concept/Early Planning

Operational fixed-bottom projects

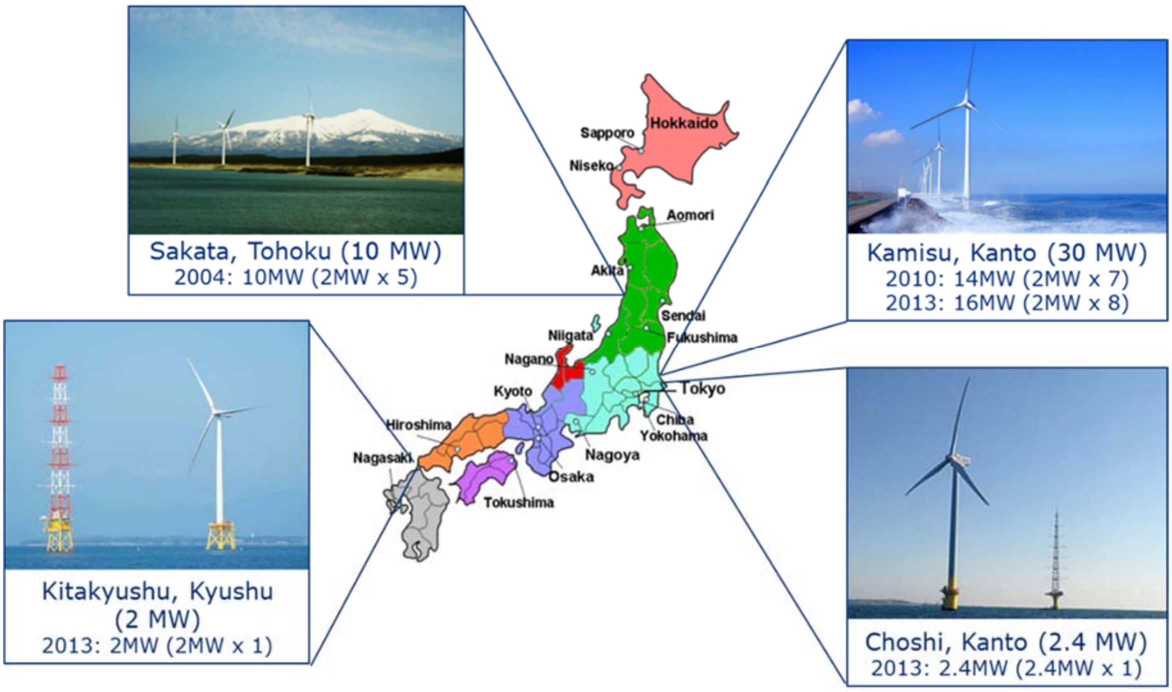
The first offshore wind farms were installed in 2004, in Sakata (Tohoku) and Setana (Hokkaido) respectively. Both were installed close to shore on high-rise pile cap foundations, common in onshore wind farms. Indeed, Sakata wind farm, consisting of 5 x 2 MW turbines located offshore, also includes 3 x 2 MW turbines located onshore. There are plans to increase capacity to 37 MW.

Kamisu Nearshore Wind Farm, commissioned in 2010, mirrored this close-to-shore layout, with 7 x 2 MW turbines lining the immediate coastline of Kashima Port. Kamisu was extended to 15 x 2 MW turbines in 2013, making it Japan's largest offshore wind farm, and there are plans to add another 100 turbines, which would increase total capacity to over 500 MW. Hitachi have been awarded consent to install a 5 MW demonstration turbine in the area, which will catalyse more activity if successful. This is in part driven by Yamagata Prefectural Government's energy strategy to increase renewable electricity production from 2% in 2010 to 25% by 2030. The site is being developed by Wind Power Energy (North) and Marubeni Corporation (South).

Japan's first truly offshore turbines were installed in Choshi and Kitakyushu, respectively, in 2013. Both demonstrations were commissioned by NEDO as part of a major R&D initiative to develop understanding and capability in developing wind farms offshore. The sites, located on either side of mainland Japan, are both subject to challenging marine conditions and will provide good coverage of the design requirements necessary for offshore wind projects in Japan, as well as first experience of the installation and O&M challenges of developing wind farms offshore (NEDO, 2013).

The project at Choshi, just 25km south of Kamisu Nearshore Wind Farm, is installed 3km off the coast in 12m water depth, consisting of a gravity base foundation supporting a 2.4 MW Mitsubishi turbine. The demonstration, jointly developed with TEPCO, also includes a met mast observation tower to collect data on the offshore environment, including wind resource and ocean swells. The project at Kitakyushu, co-developed with J-Power, represents a 2 MW Japan Steel Works turbine, together with a met mast observation tower, located 1.4km off the coast in 14m deep water. The turbine and met mast are both supported by a novel hybrid gravity-base/jacket foundation. Comparisons between the data collected at each site will provide a useful benchmark for future projects.

Figure 15. Operational fixed-bottom projects in Japan



Pipeline fixed-bottom projects

In addition to the extension projects documented above in Kamisu (Kashima Port) and Sakata, there are a number of other fixed-bottom offshore wind projects in the pipeline, all located within 4km from shore in water depth up to 20m:

- Mermaid Project: Sasebo Heavy Industries are planning to install two demonstration suction bucket foundations off the coast of Nagasaki, through the "Mermaid Project", initially with a 2 MW turbine before scaling up to a 5 MW turbine (Sasebo Heavy Industries, 2013).
- Shimonseki: Maeda Corporation hope to develop a 60 MW wind farm in Shimonseki, with construction expected to start in 2015 and a view to coming on line in 2017. Local acceptance has been confirmed and environmental assessment procedures have commenced.
- Mutsu Ogawara: Wakachiku are heading up a consortium with plans to develop an 80 MW wind farm in the port area of Mutsu Ogawara, Aomori, consisting of 32 x 2.5 MW turbines. Local acceptance has been confirmed and project planning is underway, with construction expected to start in 2016 and complete in 2018.
- Ishikari Bay: Green Power Investment Corporation plan to build the first truly offshore wind farm in Hokkaido, with 100 MW capacity.
- Omaezaki: Shizuoka Prefecture hope to build a 40 MW wind farm in the Omaezaki port area, consisting of 9 x 4.5 MW turbines.
- Akita "Kingdom of Wind": Obayashi Corporation and Kokusai Kogyo plan to co-develop a demonstration project in Akita consisting initially of 3 x 3.5 MW turbines, but with a view to potential expand to as many as 1000 turbines.
- Aqua Commercialisation Study Group: Consortium of 7 companies planning to develop a project consisting of 3 x 2.5 MW demonstration turbines with jacket foundations in Tsugaru, Aomori.

Floating offshore wind projects

The Japanese government has been investing in research on floating structure technologies for more than 20 years (Bossler A. , 2012). Until recently, most of the research has been government funded, but since the Fukushima nuclear accident, offshore wind is being incentivised, hence attracting technology developers as well. The country's growing know-how will give Japan a competitive advantage over other countries and put it in a strategic position to enter international markets, such as the U.S, where the deep sea offshore wind potential is huge.

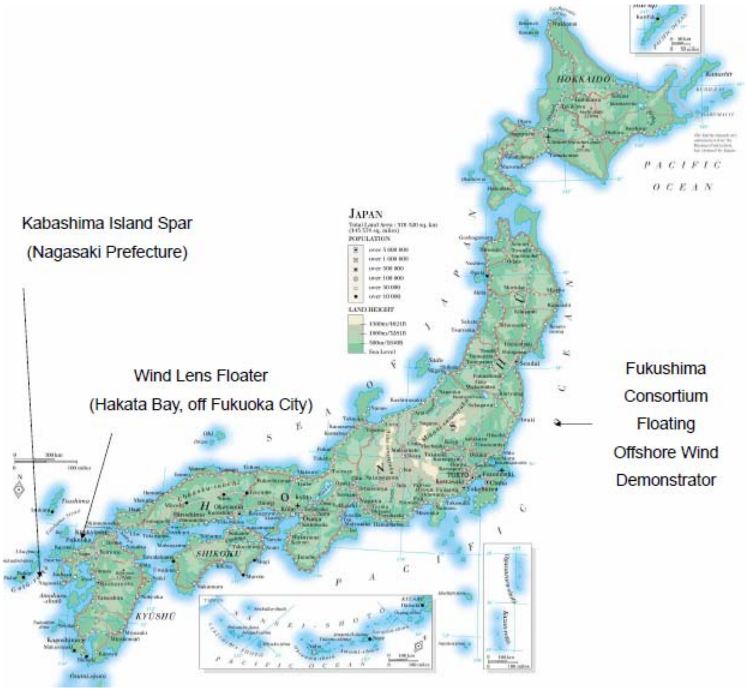
There are currently three floating offshore wind projects in the regions of Kyushu and Tohoku:

- GOTO FOWT, Kabashima Island (Kyushu)
- Fukushima FORWARD (Tohoku)
- WindLens (Kyushu)

Table 2. Details of floating offshore wind projects in Japan (installed and pipeline) (4coffshore, 2013).

Name	Region	Project size (MW)	Turbine size (MW)	Turbine manufacturer	Foundation type	Operational	Status
Kyushu University Wind Lens Project - Phase 1	Kyushu	0.006	0.003	RIAMWIND	Semi-sub platform	201	Fully Commissioned
Kabashima GOTO FOWT Floating Offshore Wind Turbine - 2 MW	Kyushu	2	2	Hitachi/Fuji	Spar Floater	201	Fully Commissioned
Fukushima Floating Offshore Wind Farm Demonstration Project - Phase 1	Tohoku	2	2	Hitachi/Fuji	Semi-sub platform	2013	Fully Commissioned
Savonius Keel & Wind Turbine Darrieus [skwid]	Kyushu	0.5	0.5	MODEC	Semi-sub platform	2013/14	Consent Authorised
Kyushu University Wind Lens Project - Phase 2	Kyushu	1.5	0.35	RIAMWIND	Semi-sub platform	2014/15	Consent Authorised
Fukushima Floating Offshore Wind Farm Demonstration Project - Phase 2	Tohoku	14	7	Mitsubishi	Semi-sub and spar (1 of each)	2014/15	Concept/Early planning
Fukushima	Tohoku	1000	7	Not decided	Semi-sub platform	Unclear	Concept/Early planning
Kabashima GOTO FOWT Floating Offshore Wind Turbine - 100 kW	Kyushu	0.1	0.1	Fuji Heavy Industries	Spar Floater	2012	Decommissioned

Figure 16. Floating offshore wind turbines project locations (Main(e) International Consulting LLC, 2013)



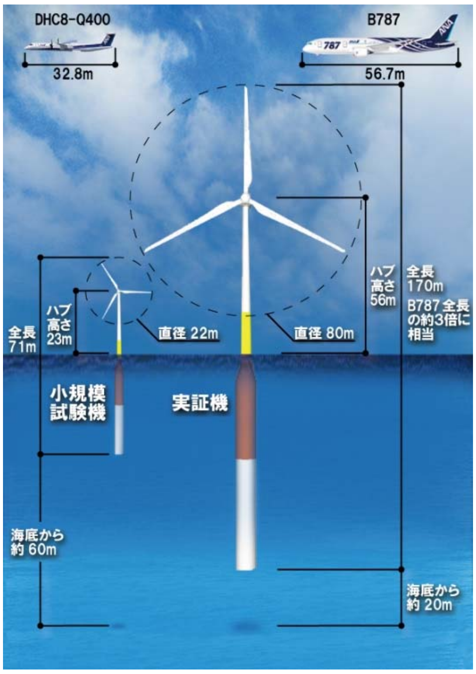
Kabashima GOTO FOWT Floating Project

The first grid-connected wind turbine was installed off Kabashima Island (Goto City) in the Nagasaki Prefecture in 2012. It consisted of a small-scale 100 kW floating spar buoy installed 1km from Kabashima Island (GOTO FOWT, 2013). Japan's Ministry of Environment funded the project in which Kyoto University, Fuji Heavy Industries, Toda Construction, and the National Maritime Research Institute of Japan collaborated in its development. The test plant used a floating spar buoy built by Japan Steel Works and Hitachi.

Following the small scale demonstration plant, the next phase of the GOTO FOWT project consisted of replacing the 100 kW plant with a 2 MW Fuji Heavy Industries turbine, again with a floating spar buoy, which was installed at the end of October in 2013 (Global Wind Energy Council, 2013), making it the first grid connected floating offshore turbine in Japan. Generated power will be supplied by connecting it to the Kyushu Electric Power Co., Inc.

Kabashima is also an excellent location to test for typhoon resilience, since the typhoons in this southern part of Japan are much more severe than further north, at Fukuhsima. For example, the area was hit by Typhoon Sanba in September 2012, which caused extensive damage locally, but the Fuji turbine emerged relatively unscathed. This was the first floating turbine to take a direct hit from a storm of such size (Recharge, 2014).

Figure 17. Scale-up from 100kW to 2MW turbine, supported by a floating spar buoy (GOTO FOWT, 2013)



Fukushima FORWARD Project

In March 2011, the Japanese government announced its intentions to build the largest offshore wind farm in the Fukushima prefecture. The expected target is to produce more than 1 GW of wind power by 2020, which would far exceed the capacity of UK's current biggest wind farm, the London Array (630 MW) (Euronews, 2013). The Fukushima FORWARD consortium consists of 11 organisations, coordinated by Marubeni Corporation, and include the University of Tokyo, Mitsubishi Corporation, Mitsubishi Heavy Industries, Japan Marine United Corporation, Mitsui, Nippon Steel, Hitachi, Furukawa Electric Co., Shimizu Corporation, and Mizuho Institute. The project is sponsored by Japan's METI.

The first phase of the project consisted on installing a 2 MW floating wind turbine 20 km off the coast and the first 66 kV floating substation and undersea cable. Installation was completed towards the end of 2013. During the second phase of the project, two 7 MW floating turbines will be installed in 2014-2015 (Fukushima Offshore Wind Consortium, 2013). The turbines will be located in deep waters (100-200 m) with waves of 7-14 m in height (Bossler A. , 2012). The power generated will be transmitted to the Tokyo area using existing grid lines (Offshore Wind, 2013). The Fukushima demonstration project will be key in the development of Japan's offshore wind industry.

Figure 18. Fukushima Forward Project timeframe (Fukushima Offshore Wind Consortium, 2013)

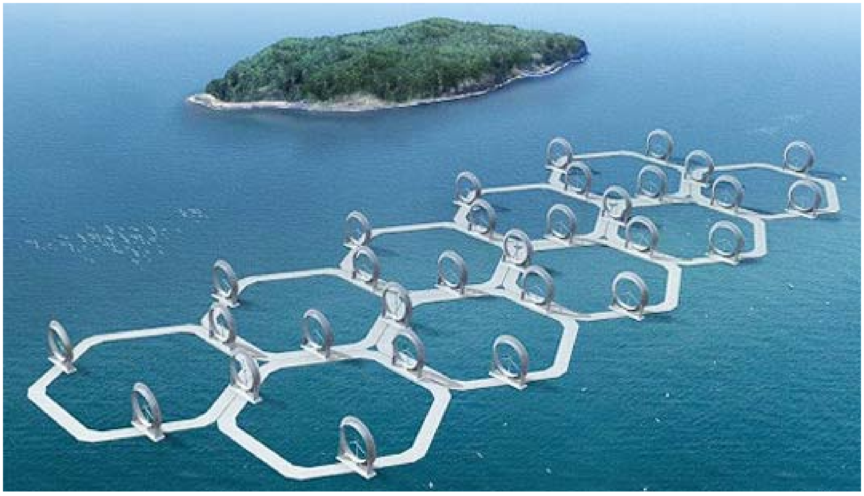
WindLens Project

The WindLens project, led by Kyushu University, was launched in 2011 to test an 18 m diameter floating turbine platform with two 3 kW WindLens turbines. The platform, installed 600m from shore In Hakata Bay, also includes solar photovoltaic panels (1.5 kW) (Ohya, 2012). The WindLens design consists of an inward curving ring surrounding the blades as they rotate. Due to the increased pressure, the power output can be doubled (Eartheasy, 2012).

Figure 19. Kyushu University WindLens (www.power-technology.com)

The second stage of the project consists on installing a larger, 60m diameter platform, farther from the coast (2km) with 2x 350 kW and 3x 200 kW WindLens turbines. The future platform system intends to combine power generation systems such as wind, solar, tidal and wave.

Figure 20. Future concept design for a large scale WindLens array (www.inhabitat.com)



2 Policy & Regulatory Framework

Japan's Basic Energy Plan, which was revised in 2010, estimated that 20% of the electricity generated in 2030 would come from renewable sources, covering 13% of the total primary energy supply. Nuclear power was expected to generate about 50% of the electricity demand in 2030, a considerable increase from its less than 30% share in 2010. Being a resource constrained country, the increase in nuclear's share would have been necessary to achieve the target of doubling Japan's energy self-sufficiency ratio to 40% (Ministry of Economy, Trade and Industry, Japan, 2010).

The Fukushima accident marked a turning point for Japan, calling for a revised Strategic Energy Plan as the Japanese Government confirmed its intentions of reducing its nuclear energy dependency as much as possible. On June 2012, the Government issued the "Options for Energy and Environment" document, in which it evaluated three long-term energy scenarios: 0%, 15%, and 20-25% of nuclear power share. According to Duffield and Woodall, METI estimates that the share of renewables in Japan's primary energy supply will be less than 12% in 2030 (Vivoda, 2012).

Since the Fukushima accident, only two nuclear reactors have been re-commissioned (in July 2012), but they were shut down again in 2013, leaving Japan with no nuclear power generation (U.S. Energy Information Administration, 2013). Although there is still mounting public pressure to move away from nuclear energy, Japan's current Prime Minister, Shinzo Abe, has indicated plans to restart those reactors that were assessed to be compliant with the safety standards established by the nuclear regulator (Iwata, 2013).

The Fukushima nuclear disaster has also impacted on Japan's carbon emission goals. Back in 2009, Japan had announced a 25% reduction in CO_2 emissions by 2020 compared to 1990 levels. However, more recently at the 2013 UN Climate Change Conference of Parties in Warsaw, Japan announced a new target, which implies an increase in CO_2 emissions rather than a reduction. The new target consists of a 3.8% cut in CO_2 emissions by 2020 compared to 2005 levels. Comparing it to the same 30 year time period, the new target translates to a 3% increase compared to 1990 levels (Soble & Cienski, 2013). The Japanese government justifies this target adjustment due to the difficulties faced to use low carbon electricity after having to shut down nuclear power plants, and in turn rely for the most part on fossil fuels.

2.1 Feed-In-Tariff

Japan introduced a Renewable Energy Portfolio Standard (RPS) in 2003, which was later replaced by a feed-in-tariff scheme to incentivise private investment in the renewables sector by offering highly competitive fixed long-term rates. (OECD, 2013). The RPS required electric power companies to source a specific proportion of their electricity from renewable sources without fixed prices (Goto, 2013). The initial target of the RPS was 12.2 TWh of renewable sourced electricity by 2010, corresponding to about 1.35% of total production (Innovation Norway, 2013). Subsidies for the RPS scheme were terminated in 2010, but a feed-in-tariff policy was approved to increase the deployment of renewable energies in 2011, and came into place in July 2012. The purchase price and period, published by METI, were dependent on the renewable technology in question. According to the brokerage firm CLSA, revenues related to renewable energy will be more than $30 billion by 2016 (Inoue & Walet, 2012).

With regard to wind power, onshore wind in Japan is benefiting from a generous FIT compared to other countries like the U.K., China and Germany. For instance, onshore wind power installations >20 kW benefit from a purchase price of $0.23/kwh for 20 years, compared to $0.11/kwh for 5 years in Germany (Ministriy of Environment, Trade and Industry, Japan, 2013) (Deutsche Bank Group, 2012). With this in mind, CLSA expects wind power capacity in Japan to reach 7.6 GW in 2016 (Inoue & Walet, 2012). However, the tariff is considered far too low to incentivise offshore wind power. Up until 2014, both onshore and offshore wind had the same purchase price (¥23 /kWh), but in April 2014 METI announced a new feed-in tariff to account for the higher costs of offshore wind technology, increasing the tariff by over 50% to ¥36 /kWh. Despite this increase to a subsidy that far exceeds others around the world, it is unclear whether this will provide sufficient returns for investors, with some developers claiming that ¥40 /kWh will be necessary to kick-start the industry in Japan, due to higher base costs and a lack of suitable infrastructure and offshore experience in Japan.

Table 3. Wind power subsidies (Japan Renewable Energy Foundation, 2013) (Deutsche Bank Group, 2012) (Carbon Trust, 2013)

Wind power	Japan	UK	Germany	China
Onshore	<20 kW: ¥57.8/kWh **(US$ 0.57/kWh)** ≥20 kW: ¥23.1/kWh **(US$ 0.23/kWh)**	EITHER: 0.9 Renewable Obligation Certificates (ROCs) + wholesale price elec. (for 20 years) Typical price = ~£90-100/MWh[1] **(US$ 0.15-0.17/kWh)** OR: Contracts for Difference (CfD) (for 15 years). Strike prices: £95/MWh (2014-17) **(US$ 0.16/kWh)** £90/MWh (2017-19) **(US$ 0.15/kWh)**	€0.089/kwh **(US$ 0.11)** for the first 5 yrs., Then €0.048/kwh **(US$ 0.06)**	Group I: ¥0.51/kWh **(US$ 0.08/kWh)** Group II: ¥0.54/kWh **(US$ 0.09/kWh)** Group III: ¥0.58/kWh **(US$ 0.09/kWh)** Group IV: ¥0.61/kWh **(US$ 0.10/kWh)**

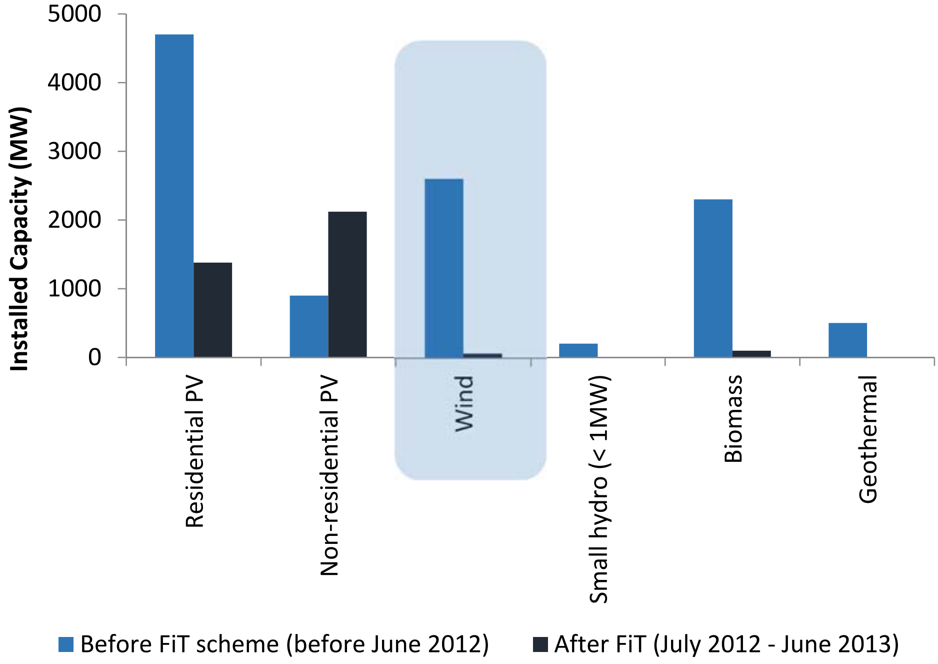
[1] Price is variable, determined by ROC auction and wholesale price of electricity. Typical price quoted assumes: 1 ROC = ~£40-50/MWh; wholesale price of electricity = ~£50/MWh.

Offshore	¥36/kWh **(US$ 0.35/kWh)**	EITHER: 2 ROCs[2] + wholesale price elec. (for 20 years) Typical price = ~£140-150/MWh[1] **(US$ 0.24-0.25/kWh)** OR: Contracts for Difference (CfD) (for 15 years). Strike prices: £155/MWh (14/15&15/16) **(US$ 0.26/kWh)** £150/MWh (16/17) **(US$ 0.25/kWh)** £140/MWh (17/18&18/19) **(US$ 0.24/kWh)**	EITHER: €0.15/kwh **(US$ 0.20/kWh)** for 12 yrs OR: €0.19/kwh **(US$ 0.25/kWh)** for 8 yrs THEN: €0.035/kwh **(US$ 0.05/kWh)** *N.B. Duration of high tariff can be extended dependent on site conditions.*	Inter-tidal = 0.75 CNY/kWh **(US$ 0.12/kWh)** Offshore = 0.85 CNY/kWh **(US$ 0.14/kWh)**
Period	20 yrs.	ROC = 20 yrs; CfD = 15 yrs	Variable	

After the introduction of the renewable FITs in 2012, Japan saw an additional 3.7 GW of renewables installed capacity. The FIT had an extremely positive impact on solar PV applications, which have accounted for 95% of the new renewable installed capacity since the introduction of the scheme (Japan Renewable Energy Foundation, 2013). The dominance of solar PV over wind is largely attributed to the shorter time to market, partly due to faster fabrication and installation, but in Japan largely due to the rigorous environmental impact assessments which are mandated for wind power, but exempt for solar PV. Thus, many applications for onshore wind projects have been subjected to 3-4 year delays and will only come online from 2015 or 2016.

[2] ROCs for offshore wind will be reduced to 1.9 ROCs in 2015/16 and 1.8 ROCs in 2016/17.

Figure 21. Renewable energy installed capacity in Japan after establishing the FIT scheme (Japan Renewable Energy Foundation, 2013)



2.2 Electricity reform

Japan's electricity sector is dominated by nine regional, vertically integrated utilities. A partial market deregulation was seen on 1995, allowing new wholesale suppliers and Independent Power Producers (IPPs) to generate and deliver electricity to the electric utilities. However, despite the reform there was little transformation in the way electric utilities operate (Innovation Norway, 2013). In 2003, the Japan Electric Power Exchange (JPEX) was established with the aim of promoting transactions in the wholesale market (Jones & Kim, 2013). However, even with the reform, it was not possible to unbundle the electricity market, that is, separation of companies' generation and sale operations from their transmission networks, due to a large opposition from the power companies. Weaknesses in the market, as well as the drastic decline in nuclear power and increased energy costs, encouraged the Japanese government to launch a new plan in 2013 to reform it and open the market to new entrants. In April 2013, a plan for a full liberation of the market was announced.

The reform has the following main objectives (Goto, 2013):

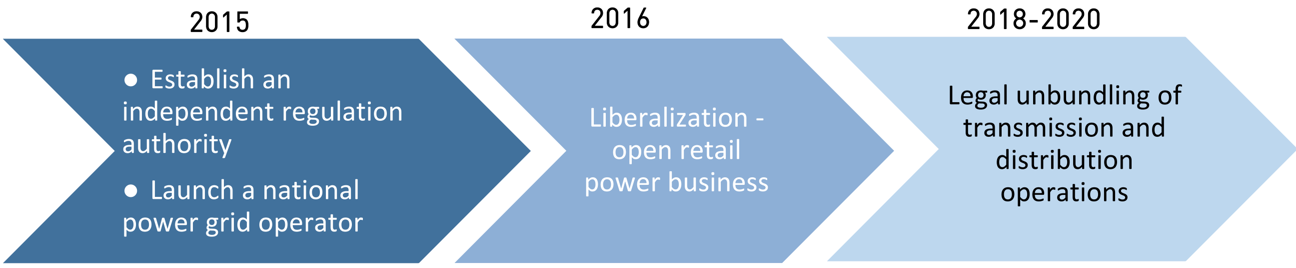
(1) Securing the stable supply of electricity

(2) Suppressing electricity rates to the maximum extent possible

(3) Expanding choices for consumers and business opportunities.

It is critical for Japan to have a competitive electricity sector by reducing the control of the regional monopolies through the unbundling of their operations and expanding the wholesale market. If this is accomplished through the electricity reform, it will aid in attracting investors and renewable energy developers. The expected roadmap is summarized in Figure 22.

Figure 22. Roadmap for electricity market reform in Japan (Sadamitsu, 2013)



The government recently set up the Organisation for Cross-Regional Coordination of Transmission Operators (OCCTO) to spearhead market reforms. OCCTO intends to liberalise the retail electricity market between 2016 and 2018, allowing consumers to choose their electricity providers. There are also plans to legally separate the utilities' generation, transmission, and distribution assets, which could be completed by 2020. However, there are concerns over the level of influence the powerful utilities will impose on the reforms (Recharge, 2014).

2.3 Policy recommendations

To incentivize the electric power companies to operate in a more competitive nationwide market, unbundling is necessary. The limited interconnection capacity between regions is an obstacle for the uptake of offshore wind energy and of renewable energies in general, as there is a mismatch between supply and demand. Increasing interconnection capacity will be critical to accelerate offshore wind deployment. Otherwise, it will be extremely challenging to transfer excess power from high-wind-low-demand areas to high-demand areas.

Policy recommendations include (Innovation Norway, 2013):

- Implement electricity market reforms to move away from the vertically integrated monopolies, which currently do not have grid expansion obligations and can refuse connection
- Increase grid interconnection capacity
- Review concession processes
    - Provide clear guidelines and relax the constraints of the Environmental Impact Assessment process for large scale wind projects, as Japan has one of the world's strictest assessments
    - Information disclosure regarding grid access refusal

Offshore wind will play a critical role in the energy future of Japan, but action is necessary to address the issues hindering private project investments. Although the government is already financially supporting wind power through the FIT scheme, it also needs to ensure the necessary infrastructure will be in place to transfer power from areas of high production and low demand, to regions of high demand. The deployment of offshore wind energy requires a strong commitment from the government to encourage private investment.

3 Costs & Financing

3.1 Cost of offshore wind power in Japan

Limited experience of developing offshore wind projects in Japan means that accurately calculating costs of future projects is difficult, particularly given the difference in costs between nearshore and offshore projects. However, cost benchmarking is necessary to identify an appropriate feed-in tariff for offshore wind, which it is hoped will stimulate growth and investment in the industry. In 2013, METI commissioned a study to set a procurement price for offshore wind power, with a view to introducing a specific feed-in tariff for offshore wind from April 2014. The study considered three different types of fixed-bottom projects, based on water depth, distance from shore, and technologies used, as well as cost estimates for Japan's two full-scale floating demonstration projects (Table 4).

Table 4. METI analysis of CAPEX and OPEX for offshore wind projects in Japan

		CAPEX (JPY/kW)	OPEX (JPY/kW)
Fixed-bottom	Scenario 1: Enclosed harbour area (cost estimate from an unnamed commercial operator).	450,000	21,000
	Scenario 2: Easy-to-build nearshore, close to port; based on projects operating in Japan and overseas.	540,000 - 590,000	15,000 - 30,000
	Scenario 3: Deeper waters; more developed technology - larger turbines and more expensive foundations.	790,000	23,000
Floating	Scenario 1: Based on wind farms consisting of 20-50 turbines, using data from demonstrations at Fukushima and Kabashima.	1,120,000	31,000

Of the fixed-bottom scenarios assessed, METI claim that the estimates produced for scenarios 2 and 3 are the most realistic, claiming that scenario 1 "is not sufficient to forecast potential commercialisation risks and facility utilisation rates" (RechargeNews, 2014). This puts the cost of offshore wind at roughly 2-3 times more expensive than onshore wind (CAPEX = 300,000 JPY/kW; OPEX = 6,000 JPY/kW (Maine International Consulting, 2012). However, costs could vary significantly depending on specific geographical conditions, as well as the kinds of turbines and foundations used.

The fixed-bottom costs are also slightly more expensive than in Europe. For example, capital costs for European wind farms are typically around £3m/MW (500,000 JPY/kW), below the lower estimate for even nearshore Japanese projects. The higher costs in Japan are therefore likely to reflect the more nascent state of the industry and the lack of an established supply chain. It is expected that the costs for fixed-bottom turbines will decrease over time as the level of installed capacity increases.

Floating technology is significantly more expensive than fixed-bottom projects, and the METI estimate already accounts for significant cost reductions from the Fukushima and Kabashima demonstrations. For example, manufacturing and installing the 2 MW turbine for the first phase of the Fukushima Forward project cost just over 2 million JPY/kW. The second phase hopes to reduce this cost by half, to 1 million JPY/kW; however, costs would need to drop further to 700,000-800,000 JPY/kW for floating offshore wind farms to become commercially viable versus fixed-bottom structures, and long-term it is hoped that costs can be reduced as low as 500,000 JPY/kW to become commercially attractive versus other energy sources (Bloomberg, 2013b).

Feed-In Tariff

As explained in section 2.1, up until recently, offshore wind and onshore wind have enjoyed the same feed-in tariff of 23.1 JPY/kWh over 20 years, a level which is unable to provide a return for more expensive offshore projects. However, in April 2014 METI announced a new FIT for offshore wind, which increased the subsidy to 36 JPY/kWh. At nearly 60% premium to onshore wind, this will provide better returns for offshore developers; however, this may still fall short of the 40 JPY/kWh some members of industry expect will be necessary to drive significant growth in offshore wind (Sasebo Heavy Industries, 2014).

The cost estimates for floating offshore wind projects are significantly higher than those for fixed-bottom wind farms. The FIT announced in April 2014 is therefore for fixed-bottom projects only. However, a tariff for floating offshore wind power could come in to play following the next phase of the Fukushima project, after which there will be more data to perform more accurate cost benchmarking.

Long-term cost competitiveness of floating turbines

The cost of floating turbines is expected to become increasingly competitive with fixed-bottom foundations over time, particularly at water depth >50m. While capital costs for foundations and turbines is expected to remain high, in line with fixed projects, there is significant potential to reduce installation costs relative to fixed-bottom foundations (Table 5). While fixed-bottom turbines require heavy lift vessels (HLV) and jack-ups, and often additional equipment such as piling hammers, floating turbines can be assembled at port and floated out to site using standard anchor handling tugs (AHT). Mobilising these smaller vessels is also far cheaper than the large bespoke vessels required for fixed-bottom installation. Another benefit is that installation of floating structures is less sensitive to weather conditions, reducing costly delays. In combination with more expensive foundation costs, the savings made through cheaper installation brings the capital cost of floating turbines almost in line with fixed turbines at 45m depth (Table 6). The greater the water depth, the more cost competitive this will be.

Table 5. Comparison of expected installation costs for fixed and floating foundations (GL Garrad Hassan, 2012)

Fixed	Cost	Floating	Cost
HLV for foundation installation	150-500 k€ /day	Standard AHT for mooring installation	150-500 k€ /day
Jack-up for turbine erection (5-7 MW)	150-200 k€ /day	Standard tugs for tow-out and hook-up	150-500 k€ /day
Mobilisation	Several M€	Mobilisation	<100 k€

Table 6. Comparison of expected future CAPEX for jacket and floating foundations (GL Garrad Hassan, 2012)

Cost (M€/MW) 'typical' Floater & jacket 45 m w-depth		*Steel prices*			
		low		*high*	
		Fixed	*Floating*	*Fixed*	*Floating*
Vessel dayrates	*low*	3.9	4.1	4.1	4.5
	high	4.1	4.2	4.2	4.6

Operating costs are expected to be similar for minor repairs, with similar access procedures for each. However, for major repairs floating may again offer cost savings. While major repairs to fixed foundations can require expensive and slow mobilisation of jack-up vessels, floating structures can be repaired using standard tug boats which can bring the turbine back to port for repairs. While this can also be a slow process, the loss of energy production is likely to be similar, with the lower vessel cost giving overall lower OPEX for floating turbines (GL Garrad Hassan, 2012). In combination with the CAPEX above, this results in a levelised cost of energy (LCoE) which can be competitive with fixed foundations in deep waters.

Table 7. Comparison of expected future LCoE for jacket and floating foundations (GL Garrad Hassan, 2012)

LCoE (€ cent/kWh) 'typical' Floater & jacket 45 m w-depth		*Steel prices*			
		low		*high*	
		Fixed	*Floating*	*Fixed*	*Floating*
Vessel dayrates	*low*	12.2	12.4	12.5	13.2
	high	12.7	12.8	13.1	13.6

Thus, while floating technology is far more nascent and expensive than fixed-bottom structures, there is potential for floating wind farms to become competitive as the technology is proven and reaches a more mature stage of development. The technical feasibility of several concepts has now been demonstrated, and the next steps are to lower costs by modifying designs and materials and beginning to develop a supply chain and serial manufacturing processes to being deploying the designs at scale. Continued government support is expected to be necessary for the next 5-10 years, beyond which the first fully commercial projects could be developed in Japan.

3.2 Investments in offshore wind

The Japanese government estimates that at least 50 trillion yen (£401bn) will be required to install sufficient renewable energy infrastructure by 2030 if it decides to completely phase out nuclear power (Global Trader, 2013). This will require significant investment from both the public and private sector. In the absence of a competitive feed-in tariff, offshore wind projects constructed in Japan to date have benefitted from significant government funding. Different government departments have made investments in offshore wind projects, which has catalysed interest and investment from industry. For example, NEDO invested in two fixed-bottom demonstration projects at Choshi and Kitakyushu costing 5 billion yen each, which included the construction of the turbine and observation tower. The project at Choshi was developed in partnership with TEPCO, while the project at Kitakyushu was developed with J-Power (Bloomberg, 2013).

Floating demonstrations have also received significant government support, with consortiums being established to share R&D in floating technology and gain experience from developing floating projects. The Japanese government has been funding research in floating technology for more than two decades, but the level of investment is increasing as the first full-scale demonstrations come online. The floating spar buoy at Kabashima Island received 6 billion yen from the Ministry of the Environment (MOE); a project co-developed with Toda Corporation, Kyoto University, Fuji Heavy Industries, and Fuyo Ocean Development & Engineering. However, this is dwarfed by the 53 billion yen invested by METI in the Fukushima Forward project. The project is being developed by Marubeni, who is leading a consortium of 11 organisations including the University of Tokyo, Mitsubishi Heavy Industries, Japan Marine United, Mitsui Engineering & Shipbuilding, Nippon Steel, Hitachi, Furukawa Electric, Shimizu, and Mizuho Information & Research Institute.

Private consortia have also begun to develop without government support. A consortium consisting of Toshiba Corporation, Hitachi Zosen Corporation, JFE Steel Corporation, Sumitomo Electric Industries Ltd, Toa Corporation and Toyo Construction Co. Ltd. together plan to invest 120bn yen (£962m) in offshore wind over the next ten years. The firms will raise the investment funds by setting up a special-purpose company and project financing (Global Trader, 2013). While there are no immediate projects in the pipeline, this is an indication of the level of confidence in the growth of Japan's offshore wind market.

Further evidence to this growing confidence is seen in investment coming into Japan from overseas. Goldman Sachs is planning as much as 300 billion yen (US$3.19 billion) in renewable energy investments in Japan, and has identified offshore wind as a key area of focus. The US bank set up 'Japan Renewable Energy Co.' in August 2013 after Japan began offering above-market rates to producers of clean energy, following the shutdown of its nuclear reactors. Over the next five years 50 billion yen will be directly invested into clean energy projects, with 250 billion yen of loans for project financing. It is hoped that this investment will amount to about 1 GW of clean energy. While early investment focussed on the rapidly growing solar industry, the company sees offshore wind as a promising growth area (Bloomberg, 2013c).

Investment has also been evident from Japanese banks and companies in overseas markets. Japanese banks invested in European offshore wind for the first time in 2011 when Mizuho Corporate Bank and Sumitomo Mitsui Banking Corporation provided US$250 million to Marubeni Corporation to co-develop the 173MW Gunfleet Sands offshore wind farm with Dong Energy (VB Research, 2013). Marubeni has since divested half of its share to the Development Bank of Japan (DBJ), with each now holding a 24.95% stake in the UK project. It is hoped that partnering with Marubeni and Dong Energy will enable DBJ to support more renewable energy projects, both domestically and abroad (Bloomberg, 2013d).

Marubeni, which has a goal of producing 10% of its generating capacity from renewables, continued its push into offshore wind by purchasing a 25% stake in Mainstream Renewable Power for €100 million in August 2013. Marubeni also recently purchased SeaJacks, a British firm that designs and builds bespoke installation vessels for the offshore wind industry, in partnership with the state-backed Innovation Network Corporation of Japan. The US$850m acquisition was funded by a loan from six of Japan's largest banks, totalling 20 billion yen (US$252m) (JDP, 2012). Marubeni plans to integrate Seajacks into its Power Projects & Infrastructure division, strengthening its position in the offshore wind farm supply chain (Business Green, 2012).

Mitsubishi has also been active in Europe, notably through Mitsubishi Heavy Industries' joint venture with Vestas (see "Turbines" section for more) and also Mitsubishi Corporation's acquisition of several transmission assets for offshore wind farms. Starting with the Walney-1 transmission asset in November 2011, Mitsubishi Corporation (MC) has been increasing its participation in the electricity transmission sector across Europe, with other acquisitions including Walney-2 in October 2012 and Sheringham Shoal in July 2013, both in the UK. MC has also entered the electricity transmission business in Germany, having acquired BorWin-1/2 in December 2012 and DolWin-2/HelWin-2 in April of this year. Most recently, MC acquired the electricity transmission system for the London Array wind farm, which at 630 MW is the world's largest offshore wind farm. The transmission asset for the farm is valued at approximately 70 billion yen (£460 million) (Mitsubishi Corporation, 2013).

MC has also recently acquired 50% of the Luchterduinen offshore wind farm planned for construction off the coast of the Netherlands. MC will co-develop the 130 MW wind farm with Eneco, with construction expected to be completed in 2015. The two companies are also planning to work together on the Eneco-operated Prinses Amalia Windpark (Mitsubishi Corporation, 2013). In addition to managing electricity transmission assets at various offshore wind farms, the collaboration with Eneco allows MC to make a full-scale advancement into the wind generation business. Drawing on this know-how from operations in Europe will also position Mitsubishi to serve its domestic market, as offshore wind power scales up in Japan.

4 Wind Farm Development

The top wind farm developers in Japan include Energy Eurus Energy Holdings, a partially owned subsidiary of Tokyo Electric Power Company (TEPCO) and J-Power (Electric Power Development Company), operating more than 60% of the total installed wind capacity (Bossler A. , 2013). Although J-Power has only 2 MW of installed offshore wind power capacity, its total installed capacity including onshore wind farms, exceeds 350 MW (J-POWER, 2012).

Table 8. Major wind power developers and operators in Japan (onshore and offshore) (Maine International Consulting, 2012).

Developer/Operator	HQ	Ownership Structure	Geograpic Focus	Operating MW
Eurus Energy	Tokyo	Tokyo Electric Power Company, Incorporated: 60% / Toyota Tsusho Corporation: 40%	Europe (820MW), Asia (679MW), US (634MW)	537
J Power	Tokyo	Japan's larges utility company	Japan	353
CEF Clean Energy Factory Inc.	Nemuro	Private Developer (uses Vestas and GE)	Japan	195
Eco Power Company Ltd.	Tokyo	Major Sharehold Cosmo Oil Co., Ltd.	Japan	147
Summit Wind Power	Sakata	Sumitomo Group	Japan, US	36
Wind Power Ibaraki	Mito	Mitani Group	Japan	14
			TOTAL	**1,282**

Wind Power Ibaraki Ltd is currently the leading developer in offshore wind technology in terms of installed capacity, followed by Summit Wind Power and NEDO. Marubeni Corporation is expected to take a lead on offshore development, not only due to the coordination of the Fukushima FORWARD consortium, with an ambitious 1 GW of installed capacity, but it also has plans to build a 250 MW site in Kamisu, installing 50 x 5 MW fixed-turbines (4coffshore, 2013)

Table 9. Commissioned offshore wind farm developers (4coffshore, 2013)

Foundation type	Project	Developers	Region	Capacity (MW)
Fixed	Choshi Offshore Demonstration Project	NEDO TEPCO	Kanto	2.4
	Kamisu Nearshore - Phase 1	Wind Power Ibaraki Ltd	Kanto	14
	Kamisu Nearshore - Phase 2	Wind Power Ibaraki Ltd	Kanto	16
	Sakata	Summit Wind Power	Tohoku	10
	Setana	NEDO	Hokkaido	1.32
	Kitakyushu Offshore Demonstration Project	NEDO J Power	Kyushu	2

Floating	Kabashima GOTO FOWT	TODA Corporation, Kyoto University, Fuji Heavy Industries Ltf, Fuyo Ocean Development & Engineering Co.	Kyushu	2
	WindLens – Phase 1	Kyushu University RIAMWIND Corp.	Kyushu	0.006
	WindLens – Phase 1 (consent authorized)	Kyushu University, RIAMWIND Corp.	Kyushu	1.5
	Fukushima FORWARD	Marubeni Corporation, University of Tokyo, Mitsubishi Corporation, Mitsubishi Heavy Industries, Japan Marine United Corporation, Mitsui, Nippon Steel, Hitachi, Furukawa Electric Co., Shimizu Corporation, Mizuho Institute	Tohoku	2

4.1 Key turbine players in the market

The Japanese wind market is dominated by non-Japanese manufacturers, including Vestas, GE and Enercon. Local manufacturers include Mitsubishi Heavy Industries, Fuji Heavy Industry, and Japan Steel Works. According to the Japan Wind Power Association, Japan's purchases of wind turbines and parts are expected to increase from 300 billion Yen to 500 billion Yen in 2030 (Worldview, 2012).

Figure 23. Japan's wind power turbine market share in 2012 (Japan Wind Power Association, 2013) cited in (Embassy of the Kingdom of the Netherlands, 2012)

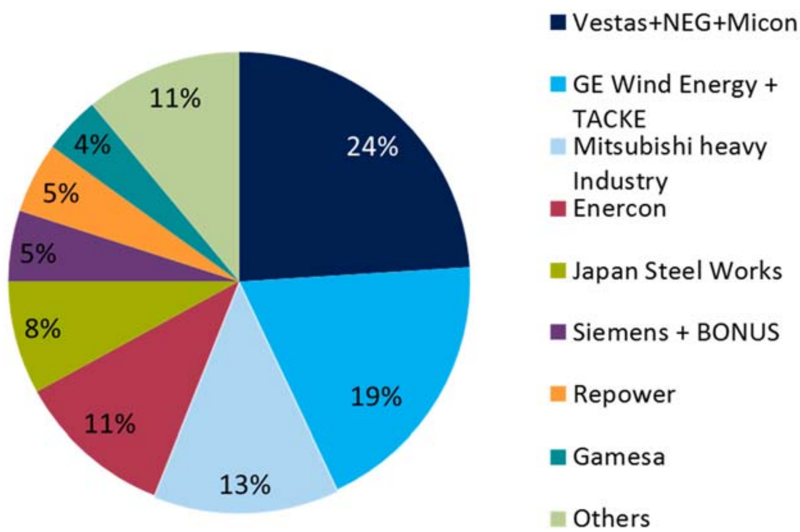


Figure 24. Major stakeholders in Japan's offshore wind power industry (Embassy of the Kingdom of the Netherlands, 2012) (Maine International Consulting, 2012)

Developers/investors	Turbines/O&M	Foundations	Installation	Utilities/ Connectivity
Marubeni Corporation	Mitsubishi Heavy Industries	Nippon Steel Corp	Mitsui Engineering & Shipbuilding Co.	Chugoku Electric Power Company
Electric Power Development Company.	Japan Steel Works	Sumitomo Metal	Japan Marine United Corporation	Chubu Electric Power
Tokyo Electric Power Co. (TEPCO)	Fuji Heavy Industries	Toyo Construction Co.	DaiiChi Kensetsu Kiko Co	Hokkaido Electric Power Company
Eurus Energy Japan	Hitachi Heavy Industries	Toa Corp.	Fuyo Ocean Development & Engineering	Kyushu Electric Power Company
Sasebo Heavy Industries	Toshiba Corporation	Toda Construction	Fukada Salvage & Marine Works	Kansai Electric Power Company
J Power	Vestas	Japan Steel Works	Yorigami Maritime Construction Co	Okinawa Electric Power Company
MAEDA Co.	RIAMWIND (WindLens)	Shimizu Corporation		The Tokyo Electric Power Company (TEPCO)
Wind Power Energy Co.	MODEC	Kajima Corp		Furukawa Electric Co.
Summit Wind Power	Siemens Japan	JFE Steel Corp		EXSYM corp
Obayashi Kokusai Kogyo	Moog	Ohbayashi		ENKAI
Komatsuzaki		Penta-Ocean Construction		VISCAS Corp
Wakachiku Co.		Hitachi Zosen		
Nippon Hume				
Green Power Investment Corp				
Japan Renewable Energy Co.				

4.2 Consenting process

Environmental Impact Assessments

The Environmental Impact Assessment (EIA) Law was introduced in Japan in 1999, but it was not until 2011 that the government extended it to include wind farm projects (Azechi, Nishikizawa, & Harashina, 2012). The Ministry of Land, Infrastructure and Transport (MILT) is responsible for the construction permitting process, while the Ministry of Environment is involved in the Environmental Impact Assessment (EIA) (Bossler A. , 2012). The environmental assessment is a complex, lengthy process, which can take between 3-4 years. As highlighted by developers, the approval process needs to be optimized to speed up the EIA studies (Watanabe, 2013) . The Japanese government has announced its intentions to relax and shorten the duration to 1-1.5 years, but if private investment and commercial developments are to be accelerated, the transition towards a more efficient process should be of immediate concern (Sasebo Heavy Industries, 2013).

The floating project is being used as a testing ground for the impact of floating turbines on marine wildlife. The Ministry of the Environment (MOE) has commissioned a study to clarify the EIA process for offshore wind farms, being led by Fuyo Ocean Development & Engineering Co. The study will assess the impact of the turbine and spar buoy on water quality, noise, bird species, and marine mammals, and it is hoped that the work undertaken at Kabashima will provide a model on which to base future EIAs for offshore wind projects (Recharge, 2014). The demonstrations at Choshi and Kitakyushu have also dedicated considerable efforts to minimise the environmental impact of these fixed-bottom projects (NEDO, 2013).

Conflict with fisheries

The social acceptance of offshore wind power by the local fishing cooperatives is necessary to increase confidence in private sector investment. By law, the cooperatives are entitled to compensation for any disturbance to their fishing operations, including turbine installation and cable laying, even outside of their designated coastal areas. These fishing cooperatives are very powerful in Japan and can exert significant influence over the consenting process. According to the Ministry of Agriculture, Forestry, and Fisheries of Japan, the fisherman's union will be able to participate in wind farm projects as a stakeholder under the Fisheries Cooperative Associations Act.

Strong collaboration is required between the fishing associations, the government and the developers. Early engagement is key, as evident in the offshore wind projects installed thus far. At Fukushima, the local fishermen were not involved from the outset, with the project being planned without their input. This led to antagonism towards the project from the fishing cooperatives, which could cause problems for gaining consent in future when trying to expand the site. Conversely, the floating demonstration installed at Kabashima has proved a success. The fishermen’s union was engaged from the start, and this early communication, combined with the promise to remove the turbine once the demo project is finished, has earned local backing for the project. Here the fishing co-ops understand the importance of the project and have agreed not to fish within a 450 square metre area of the turbine (Recharge, 2014). Developers of the demonstrations at Choshi and Kitakyushu also cited early engagement with local communities as vital to the success of their projects (NEDO, 2013).

There is also potential to adopt solutions which support marine life around wind turbines. As part of the Fukushima Forward project, the consortium is working with the fishermen's union to monitor the impact on the fishery operations. The consortium has proposed to create a new fishery farm using an automatic feeder to attract fish to the area as it were a marine pasture (Fukushima Offshore Wind Consortium, 2013) (Gilhooly, 2013). Another idea that has been evoked is to cultivate shellfish and seaweed using marine fertilization.

There is an exception to the rights of fisheries covering "Port Areas", where they have no fishing rights (Matsuura). It is therefore unsurprising that most projects installed so far have been located close to ports. The Ministry of Environment and Ministry of Land, Infrastructure, Transport and Tourism has published the "Guideline for Installation of Offshore Wind Farm in Port Area", to adopt a similar concession mechanism to the Crown Estate's scheme in the UK. Wind farm concession zones would ideally be set by the Local Government and Port Authorities, giving developers concession rights (Sasebo Heavy Industries, 2013). For example, the Ibaraki prefecture, located in the Kamisu area, ran a tender to obtain concession rights, which were then split between two developers, Wind Power Energy and Marubeni, each targeting 5MW x 50 units in 340ha (Sasebo Heavy Industries, 2013) .

The offshore wind industry also experiences opposition from the maritime industry, as they have little incentive to share the sea space because a large proportion of Japan's domestic freight is transported by coastal vessels (Bossler A. , 2013)

5 Infrastructure

5.1 Grid Connectivity

Onshore grid Capacity

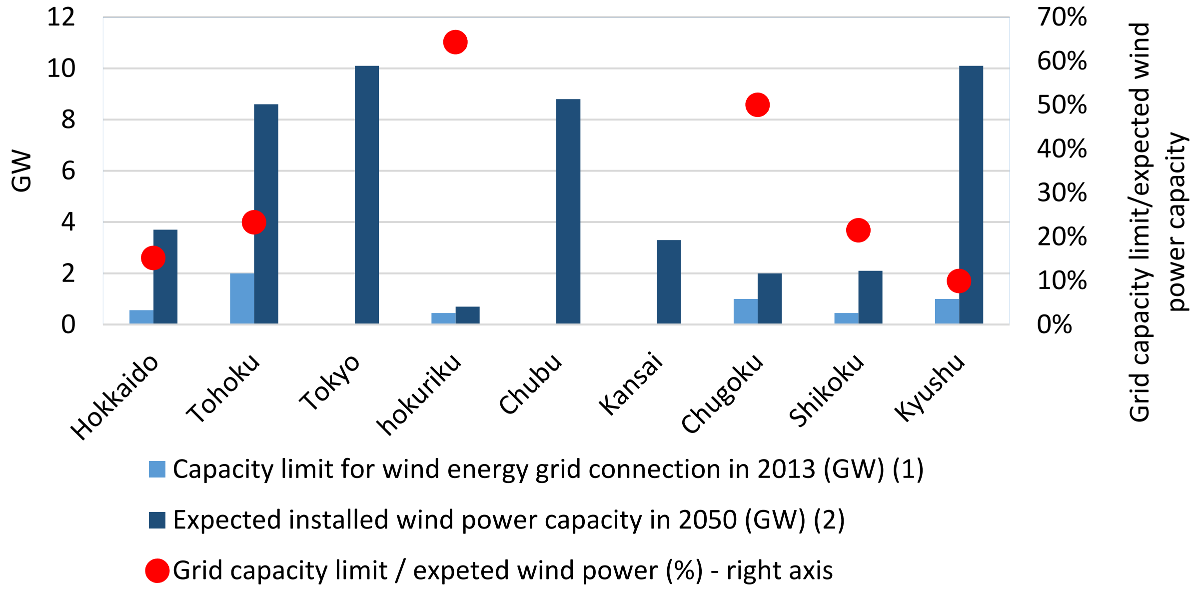
Japan faces grid and interconnection capacity issues, which if not addressed, will limit the deployment of renewable energies. Insufficient transmission capacity between the utilities is the biggest obstacle to the development of renewable energy technologies (Bossler A. , 2013). The electric power companies do not have the obligation to give priority access to renewable projects and are not obliged to expand the grid capacity, which may be seen as investors as very high risk projects (Takehama, 2012). If utilities do not expand grid capacity, there will be a further delay in the deployment of wind power in Japan. Also, if there is a general power output exceeding the demand, the electric power companies are allowed to reduce the renewable electricity being generated without compensation for up to 30 days per year (Takehama, 2012).

Grid congestion has been highlighted as an issue in Hokkaido, the northern island of Japan and in the southern areas of Chugoku and Kyushu. Meanwhile there is also a bottleneck in transmission between the different frequencies in the East and West of the country. Transferring electricity between the 60Hz frequency grid in the West to the 50Hz grid in the East relies on three transformer stations, which proved insufficient in the aftermath of the Fukushima disaster (Recharge, 2014).

According to Bloomberg New Energy Finance, Chugoku Electric Power Company and Kyushu Electric Power Company, have each less than 1 GW of available grid capacity, that is after considering existing and approved capacity. After the FIT programme was implemented in July 2012, Japan approved more than 22 GW of renewable energy capacity, while it is estimated that Japan has only 34 GW of grid availability for new solar and wind projects (Watanabe, 2013). Others estimate the current grid could accommodate 10 GW of additional wind and solar power (Berraho, 2012).

The capacity limits for wind power connection into the grid defined by the regional power companies are shown in Figure 25. Note that some of the regional companies, like Tokyo and Chubu, have not set a limit regarding wind power connection. If one compares the expected installed wind capacity in 2050 (set in the Japan Wind Power Association roadmap) with the current grid integration capacity, it is clear that major upgrades in the system are needed. Considering today's grid capacity, it would not be possible to integrate the 75 GW of wind power generation expected to be in place by 2050. Areas like Hokkaido, Tohoku, Shikoku and Kyushu need to increase more than 4 times their current grid capacity to accommodate the expected wind power in 2050.

Figure 25. Grid capacity for wind power in Japan (Takehama, 2012) (Japan Wind Power Association, 2012)



The grid capacity limit set by the electric power companies needs to be rapidly increased to accommodate the 75 GW of wind power capacity expected by 2050. It is necessary to strengthen the current grid infrastructure by building additional transmission lines and by increasing the capacity of frequency conversion stations. The cost of increasing the current conversion station from 1 GW to 10 GW is estimated to be $13.5-$20bn (Berraho, 2012). Investments in grid capacity and interconnectivity are essential to avoid bottlenecks for offshore wind development in Japan.

In response to the problem, the Japanese government is planning a massive infrastructure build-out that could lead to the rapid development of solar and wind projects in Japan's northern regions of Tohoku and Hokkaido. METI has commissioned a study with Hokkaido Electric Power to develop a JPY 50bn grid-expansion plan, of which the government would cover 50% of the funding. The plan includes grid expansion near the town of Mashike, north of Sapporo, where wind capacity potential could be up to 600 MW. METI has also revealed plans to install a massive JPY 29.6bn battery bank on Hokkaido to stabilise the flow of solar and wind power in the grid (Recharge, 2014).

An alternative option, proposed by the Japan Renewable Energy Foundation, is the creation of an Asian Super Grid (ASG), which would link the country with China, Mongolia, and Korea. Since Japan has the highest end-user electricity prices in Asia, it would benefit from lower cost electricity imports from China and Korea (Innovation Norway, 2013). If the ASG were to be established, Japan would need to undergo structural changes to allow foreign electricity suppliers into its electricity network (Vorrath, 2012).

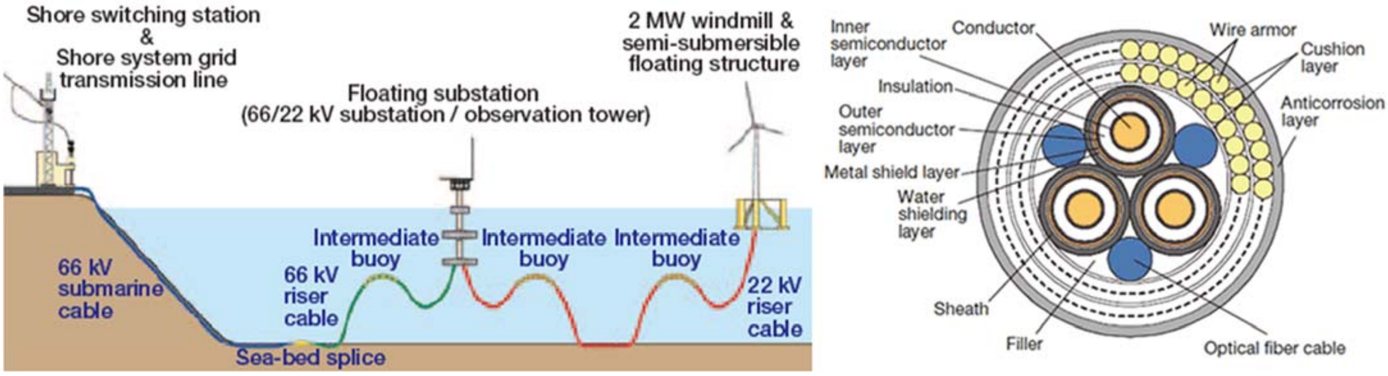
Farm-to-grid connection

The close proximity of fixed-bottom turbines to shore has meant that no offshore sub-stations have been required to date. This is expected to continue to be the case in the future, as turbines located within 5km of shore can be connected directly to an onshore substation. However, for floating turbines, which are typically located more than 10km from shore, floating substations will be needed to step up the transmission and limit losses. Japan installed the world's first floating substation for the Fukushima Forward project, supported by an advanced spar buoy developed by Japan Marine United. The substation was produced by Hitachi, with the power transmission system and sub-sea cables provided by Furukawa Electric and Viscas Corporation, respectively. Cable installation was conducted by Shimizu Corporation (Fukushima FORWARD, 2013).

Figure 26. Fukushima "Kizuna" 66kV floating sub-station (Shimizu Corporation, 2013).

The transmission system uses 66kV voltage, which reduces losses, compared to the 33kV commonly used in offshore wind farms in Europe. A special high voltage riser cable connects the substation to shore, while a lower voltage 22kV riser cable connects the substation to the turbine. The power cables are specially designed to withstand the movement and stresses of the ocean. Fixed-bottom foundations typically use j-tubes to protect cables, something which isn't possible for floating turbines. The free-hanging cables used at Fukushima are therefore designed to float in the sea and dynamically follow the movements of the floating structures. Buoys are attached at the midpoint between the floating structures to provide slack in an S-shape which adds extra length to allow the cables to move with minimal tension and stress. The cables also have excellent water-tight performance to prevent seawater penetration, as well as fatigue resistance (Furukawa Electric, 2013).

Figure 27. Diagram of cable connection layout at Fukushima (L) and structure of 66kV riser cable (R) (Furukawa Electric, 2013).



This world first design and installation of a floating offshore substation and cabling highlights Japan's position as a world leader in floating technology. While cable supply is a potential bottleneck globally, Japan has a number of suppliers which will be able to serve its domestic market, so farm-to-grid connection is not expected to be a major challenge. However, a lack of cable installation vessels may a potential bottleneck in future as deployment of offshore wind power increases (see "Installation" section for more).

5.2 Manufacturing

While Japan may not yet have an established offshore wind supply chain, there are a number of companies with suitable manufacturing capabilities to serve the industry. The three major turbine OEMs (Hitachi, Mitsubishi, and Japan Steel Works) all have existing supply chains for the onshore arms of their business, and should be able to quite easily adapt to accommodate greater production of offshore turbines. Increasing turbine size may cause challenges, particularly with regard to testing and manufacturing larger blades and drive trains; however, this isn't expected to be a major bottleneck for the industry. In the short-term, manufacturers can leverage overseas facilities (e.g. blades for Mitsubishi's 7 MW SeaAngel turbine have been manufactured and tested in Germany, while its drive trains has been developed in the UK); but if/when demand in the domestic market increases there will likely be scope to locate testing facilities and manufacturing hubs closer to home markets, in Japan.

Japan has significant manufacturing capability to fabricate offshore wind foundations, with a range of steel and construction companies looking to capitalise on growth in the industry. Likewise, while Japan has limited installation experience, there a several companies with experience of maritime engineering which can be leveraged to serve the offshore wind market. However, there is a significant amount of learning required, as well as an obvious shortage of appropriate vessels. Shipyards and shipbuilders in Japan have capability to manufacture suitable vessels, but will need a firm commitment in the size of the domestic market before it can commit the large investment needed to produce such vessels. A long pipeline of projects and strong government support are needed.

Finally, Japan has a number of cable suppliers capable of supplying the necessary 220kV export cables for offshore wind projects, as well as smaller inter-array cables. Indeed, companies such as Viscas and Exsym are already supplying cables to foreign offshore wind markets.

Table 10. Major suppliers in Japan's offshore wind industry

Turbine manufacturers	Foundation suppliers	Vessel suppliers	Cable suppliers
Mitsubishi Heavy Industries	Nippon Steel & Sumitomo Metal	Mitsui Engineering & Shipbuilding	VISCAS
Hitachi Heavy Industries	Toyo Engineering & Construction	Japan Marine United Corporation	Furukawa Electric
Japan Steel Works	Toa Corporation	DaiiChi Kensetsu Kiko	EXSYM
Toshiba Corporation	Toda Construction	Fuyo Ocean Development & Engineering	ENKAI
RIAMWIND	Fuyo Ocean Development & Engineering	Fukada Salvage & Marine Works	
MODEC	Shimizu Corporation	Yorigami Maritime Construction	
	Kajima Corporation		
	JFE Steel Corporation		
	Ohbayashi		
	Penta-Ocean Construction		
	Hitachi Zosen		

5.3 Ports

Japan has a strong maritime industry and a large number of ports along its coastline. None of these have yet been established as bespoke offshore wind ports, largely due to the early stage of the industry. However, less stringent consenting restrictions has meant that early offshore wind development has clustered around port facilities. The Kashima, Mutsuogawara and Omaezaki projects are all located at port areas, which have several advantages for offshore development in Japan. Ports are governed by only one office, the "Ports and Harbours Bureau", making permission procedure much lighter, and the fishing industry's rights are weaker at port areas, making developers freer from conflict with fishermen's unions and compensation pay-outs. Furthermore, industrial infrastructure and grid lines already exist at port facilities, reducing transport costs and logistical issues, and removing the need for expensive grid reinforcement (GWEC, 2013).

However, port location does not always align with greatest wind resource. If Japan is to exploit its most productive sites for offshore wind development, ports may need to be expanded or constructed to provide offshore wind manufacturing and installation hubs closer to site location.

Figure 28. Location of ports and harbours in Japan (Ports and Harbours Bureau, 2006)

6 Technology

6.1 Turbines

Market

The Japanese wind turbine market (onshore and offshore) is dominated by non-Japanese manufacturers, with only ~25% of turbines being supplied by domestic companies (Figure 29). This share is also dominated by a small handful of OEMs, with just two companies - Mitsubishi Heavy Industries (13%) and Japan Steel Works (8%) - accounting for over 80% of local turbine production (Figure 30).

Figure 29. Share of Japanese manufactured versus imported wind turbines (Maine International Consulting, 2012)

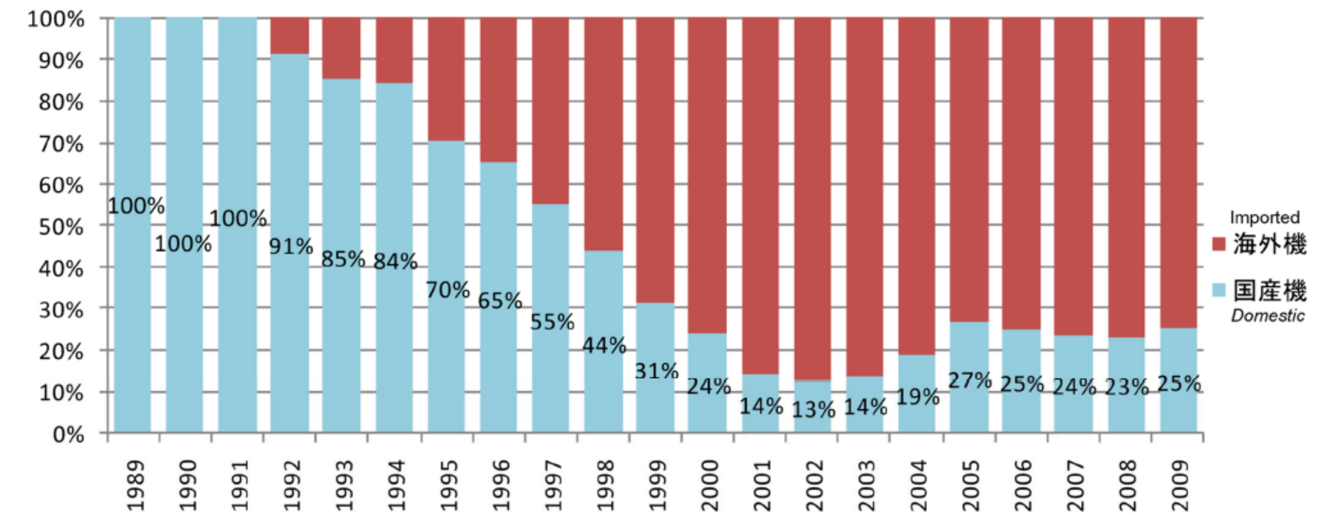
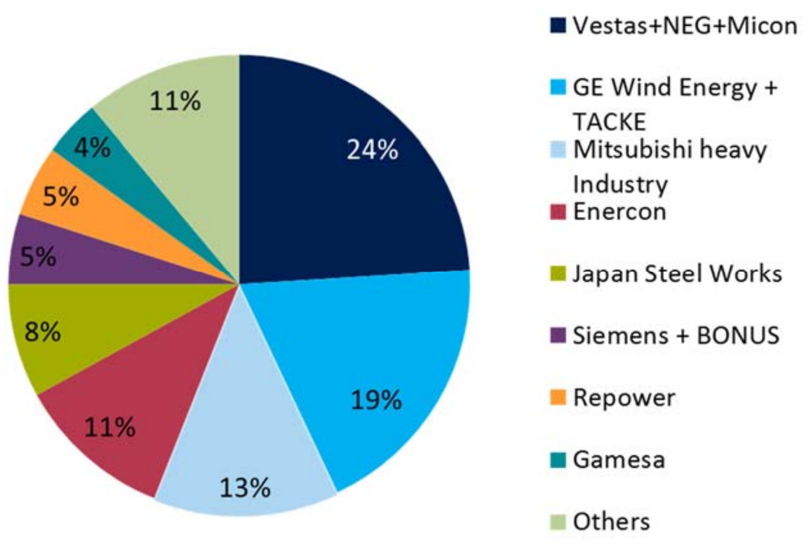


Figure 30. Japan's wind power turbine market share in 2012 (Japan Wind Power Association, 2013) cited in (Embassy of the Kingdom of the Netherlands, 2012)



In contrast to the onshore industry, turbines installed in Japan's fledgling offshore wind projects are dominated by domestic manufacturers (Figure 31), with international OEMs representing just 14%. However, again, the market is dominated by just a handful of players. While Vestas supplied the turbines for Japan's early nearshore farms in Sakata and Setana, subsequent projects have had turbines supplied exclusively from Japanese companies. Fuji developed a 2 MW offshore turbine for the Kamisu nearshore wind farm in 2010, designed specifically for the Japanese market with specifications to withstand strong winds and typhoon conditions. Fuji's wind division was acquired by Hitachi in 2012, and sales of the 2 MW model saw increased sales in 2013, with another 16 units installed in Kamisu and the first floating demonstration at Fukushima and Kabashima Island, respectively. Along with its acquisition of Fuji's wind turbine business, Hitachi has established the capabilities to handle everything from development through to design, fabrication, sales, and maintenance, and is focusing on expanding this business. Namely, Hitachi are developing a 5 MW version of the original Subaru design to be installed at scale in Kamisu nearshore wind farm from 2015, following an initial demonstration project in May/June 2014 (RechargeNews, 2013b). Hitachi has also been awarded funding by NEDO to begin conceptual designs for a 10 MW-plus model (Recharge, 2014).

Figure 31. Japan's offshore wind power turbine market share in 2013 (4coffshore, 2013)

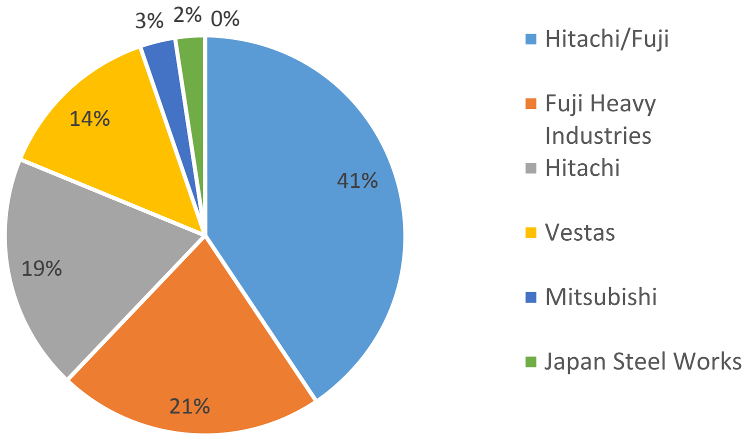


Table 11. Japanese offshore wind turbine manufacturers and models operating or being developed in Japan (4coffshore, 2013)

Manufacturer	Model	Rated power (MW)	Gearbox	Rotor diameter (m)	Commercial availability
Fuji Heavy Industries	Subaru 80/2.0	2	Geared (high-speed)	80	Available
Hitachi	HTW 2.0-80	2	Geared (high-speed)	80	Available
	HTW 5.0-126	5	Geared (medium-speed)	126	Prototype in development
Mitsubishi Heavy Industries (MHI)	MWT 92/2.4	2.4	Geared (high-speed)	92	Available
	SeaAngel 7 MW	7	Hydraulic DDT direct-drive	165	Prototype in development
	Mitsubishi 10 MW	10			Concept
Japan Steel Works	JSW J82	2	Direct-drive	83.3	Available
RIAMWIND	WindLens 3kW	0.003		2.5	Prototype
	WindLens 100kW	0.1		12.8	Prototype
	WindLens	0.2 / 0.35 / 5.0			Concept
Modec	Skwid	3		72	Concept

*N.B. Hitachi sells Fuji's Subaru branded turbines.

Figure 32. Left: Fuji Subaru 80/2.0 2 MW downwind turbine (4coffshore, 2013); Right: Artist's impression of Hitachi HTW 5.0-126 5 MW downwind turbine (Hitachi, 2013)

2013 also saw Mitsubishi Heavy Industries (MHI) and Japan Steel Works make their first forays into the offshore market, supplying turbines for Japan's first truly offshore fixed-bottom demonstrations at Choshi and Kitakyushu, respectively. Japan Steel Works developed the country's first direct-drive wind turbine - a 2 MW unit installed at Kitakyushu - and MHI provided a modified version of its 2.4 MW turbine, which was installed at Choshi.

Figure 33. Left: Japan Steel Works J82-2.0 offshore wind turbine (Japan Steel Works, 2013); Right: Mitsubishi Heavy Industries MWT 92/2.4 nacelle (Wind Power Monthly, 2012).

This is an indication of the aspiration of Japanese OEMs to become key players in the global offshore market. Mitsubishi has traditionally targeted foreign markets, with 94% of sales of its onshore wind turbines outside of Japan; however, a series of patent disputes with GE has led to falling onshore sales, and a shift in focus to entering the potentially larger prize of the growing offshore market. Notably, MHI has recently entered into a joint venture with Danish turbine manufacturer Vestas. Vestas is the world's largest wind turbine maker and Europe's second biggest offshore turbine manufacturer, with 28% of installed capacity (EWEA, 2013), and it is hoped that the joint venture will enable MHI to also boost sales in the dominant European offshore market, as well as develop capability in designing turbines for the offshore industry.

Under the agreement, Vestas will transfer the development of the V164 8 MW offshore turbine, giving MHI access to cutting edge technology. Vestas will also transfer the V112 offshore order book, existing offshore service contracts, and 300 employees. In return, MHI will inject 100 million euros ($US135 million) in cash into the JV and will inject another 200 million euros based on certain milestone achievements (RTT, 2013). MHI will also have the option to increase its stake in the joint venture to 51% in April 2016, effectively taking over control of Vestas' offshore business.

The joint venture will complement Mitsubishi's own R&D activity in developing a novel concept for a 7 MW turbine it is planning to install in phase 2 of the Fukushima FORWARD project. The "SeaAngel" turbine will be the world's first to use hydraulic drivetrain technology, developed by UK-based Artemis Intelligent Power, a company Mitsubishi bought in 2010 and that received significant support from the Carbon Trust as it was developing its technology. Indeed, the turbine's development has had a major UK influence. The development of the turbine is part of the Efficient Offshore Wind Programme (EOWP), a £33m project launched in 2012 by a consortium comprising MHI, SSE, and contractors Technip and Wood Group, following a memorandum of understanding between Mitsubishi, the UK Department for Business, Innovation, and Skills (BIS) and the UK Department for Energy and Climate Change (DECC) (Mitsubishi Heavy Industries, 2012). The first full-scale prototype is set to be installed at SSE's test site in Hunterston, Scotland (RechargeNews, 2013). Mitsubishi have also received domestic support from NEDO as part of the "Mega-Size Wind Power Development System Technology Research and Development" project, since 2011.

Figure 34. Mitsubishi Heavy Industries SeaAngel 7 MW Hydraulic CVT Direct-Drive offshore wind turbine (Mitsubishi Heavy Industries, 2012b)

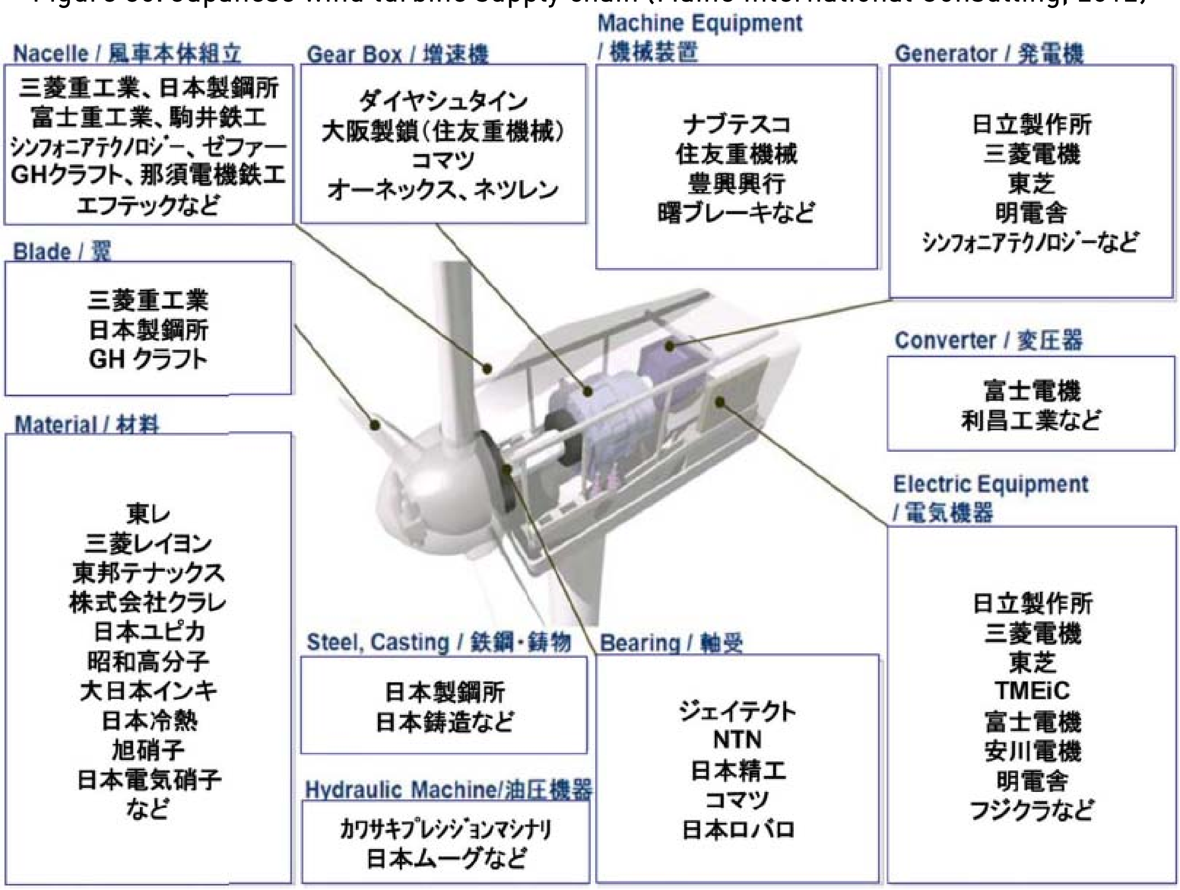
An alternative turbine concept being pioneered in Japan is the WindLens model developed by RIAMWIND and Kyushu University. The design includes a modification in the form of a ring, or "wind lens" surrounding the blades to improve wind capture efficiency. The wind lens diverts air away from the exhaust outflow behind the turbines, and this turbulence creates a low pressure zone behind the turbine, causing more wind to pass through the turbine. Two prototypes have been develop so far, a 2 x 3kW prototype tested on a floating hexagonal structure, which included solar panels, and a 2 x 100kW prototype tested onshore (4coffshore, 2013). The next phase will involve testing an 80 metre diameter floating platform 2km off the coast, with 200kW turbines. The design is still at an early R&D stage, but there are concept designs for a scaled-up 5 MW model, and the ultimate concept includes wave power in addition to wind and solar power generation (Maine International Consulting, 2013).

Figure 35. RIAMWIND WindLens 100kW prototype (4coffshore, 2013)

Supply Chain

Despite its domestic onshore wind market being dominated by international turbine manufacturers, Japan does have a wind turbine supply chain, which is selling to both domestic and non-Japanese manufacturers. There is therefore already significant capability for Japan to scale-up its production of turbines for the offshore industry.

Figure 36. Japanese wind turbine supply chain (Maine International Consulting, 2012)



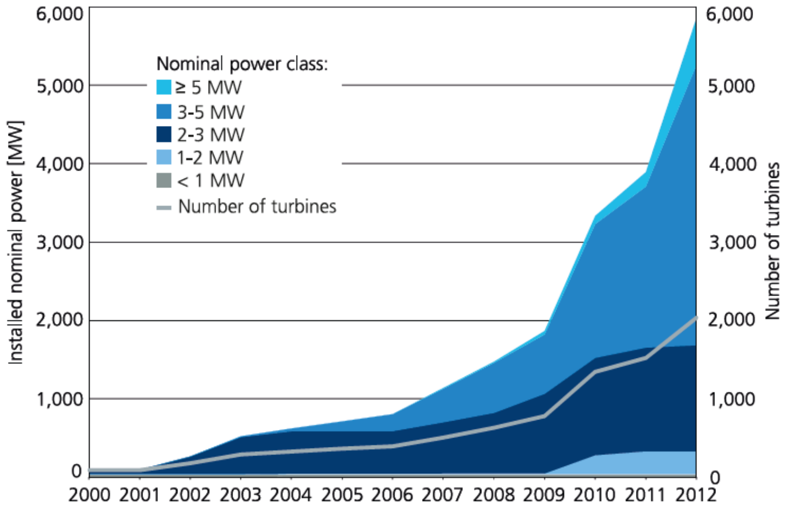
Technical challenges

Turbine size

The high construction and operating costs of offshore wind farms means that offshore wind turbines require high reliability and high output per unit. This has created a race between OEMs to develop larger turbines which can generate more energy at lower relative cost. Thus, through raising the rated power of turbines it is possible to reduce the number of turbines installed. The average nominal power of newly installed offshore wind turbines has risen from 1.9 MW in 2000 to almost 4.0 MW in 2012 (Figure 37), and there are more and more large capacity turbines becoming available for commercial use (particularly 5-6 MW), with a number of even bigger turbines in R&D (over 10 MW). However, simply scaling-up is not possible and many technical challenges are encountered as power rating and size increase.

Reliability is also a critical issue, since it is a huge driver towards project economics. Low rates of availability will have a direct impact on yield and require repairs and maintenance further offshore that will increase costs. Developers are therefore likely to favour higher quality and performance over price.

Figure 37. Cumulative nominal power and number of offshore WTGs worldwide (Fraunhofer, 2012)

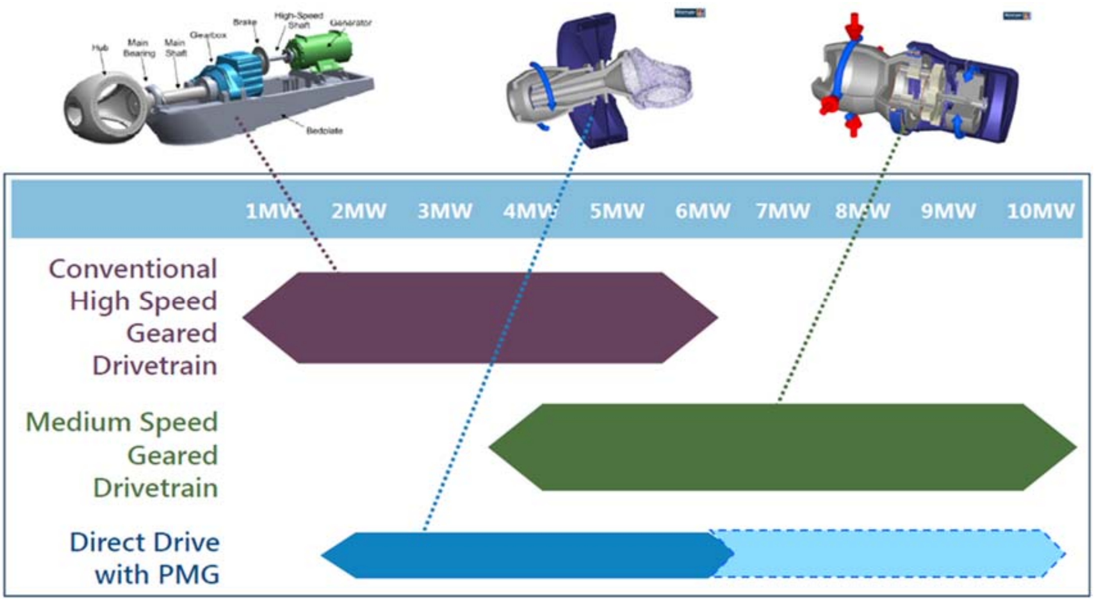


Drive train

Low capacity offshore turbines originally had high-speed geared drivetrains; however, increasing power output is limited by higher ratio requirements and physical limitations. Namely, as turbine size increases, the longer blades result in slower rotations of the main shaft, applying greater pressure on the gearbox to convert these slow rotations into the fast rotations necessary for the generator. As such, high speed gearboxes tend to suffer reliability issues. Medium speed gearboxes, with smaller gear ratios, are therefore favourable for large capacity turbines. For example, the Mitsubishi MHI 2.4 MW and Fuji/Hitachi Subaru 2.0 MW turbines both used high speed geared drivetrains; however, the scaled-up 5 MW version of the Subaru model will adopt a medium-speed gearbox. The 5 MW model will also include a more compact drive train using a permanent magnet synchronous generator, which is more efficient than the doubly fed generators used in the high-speed drive train of the 2 MW version.

An alternative approach being adopted by an increasing number of OEMs is to remove the gearbox altogether, connecting the generator directly to the main shaft. The nature of variable wind speeds means that the gearbox is subjected to unpredictable force variations, with bearings in particular subject to significant torque. While direct-drive systems are larger and heavier than geared alternatives, they are expected to improve reliability due to fewer moving parts in the nacelle. Given the expensive cost of repairing a gearbox, particularly at sea, moving to direct-drive is an attractive proposition for many manufacturers. For example, Japan Steel Works has developed a 2 MW direct-drive turbine for offshore operations, which was installed at the Kitakyushu demonstration project. The drive train in the turbine is comprised of a comparatively small number of parts, resulting in fewer breakdowns and lower maintenance costs. The turbine is also equipped with a high efficiency permanent magnet synchronous generator, which eliminates the need for any step-up gear or abrasion parts such as brushes. As well as eliminating gear failures, removing the gearbox reduces noise and removes the need for oil lubrication and regular gearbox maintenance (Japan Steel Works, 2013).

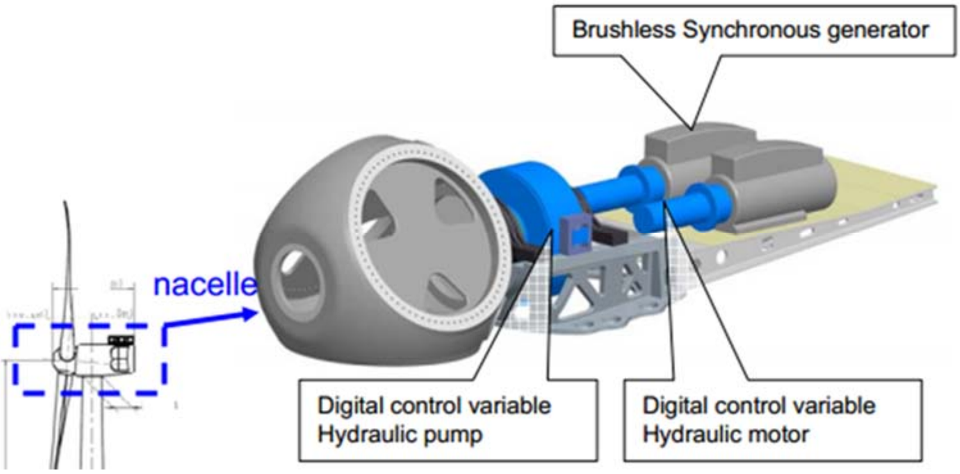
Figure 38. Drive train applicability versus nominal power output (Romax, 2011)



However, direct-drive turbines do impose a greater challenge with regard to the generator. While there are fewer moving parts than geared drive trains, generators in direct-drive machines require increasing the number of poles, complexity, size, weight, and price of the component (LORC, 2013). The latter is largely due to the amount of rare earth metals required in the generators, which are extremely costly, particularly as turbines size increases beyond 6 MW (Romax, 2011).

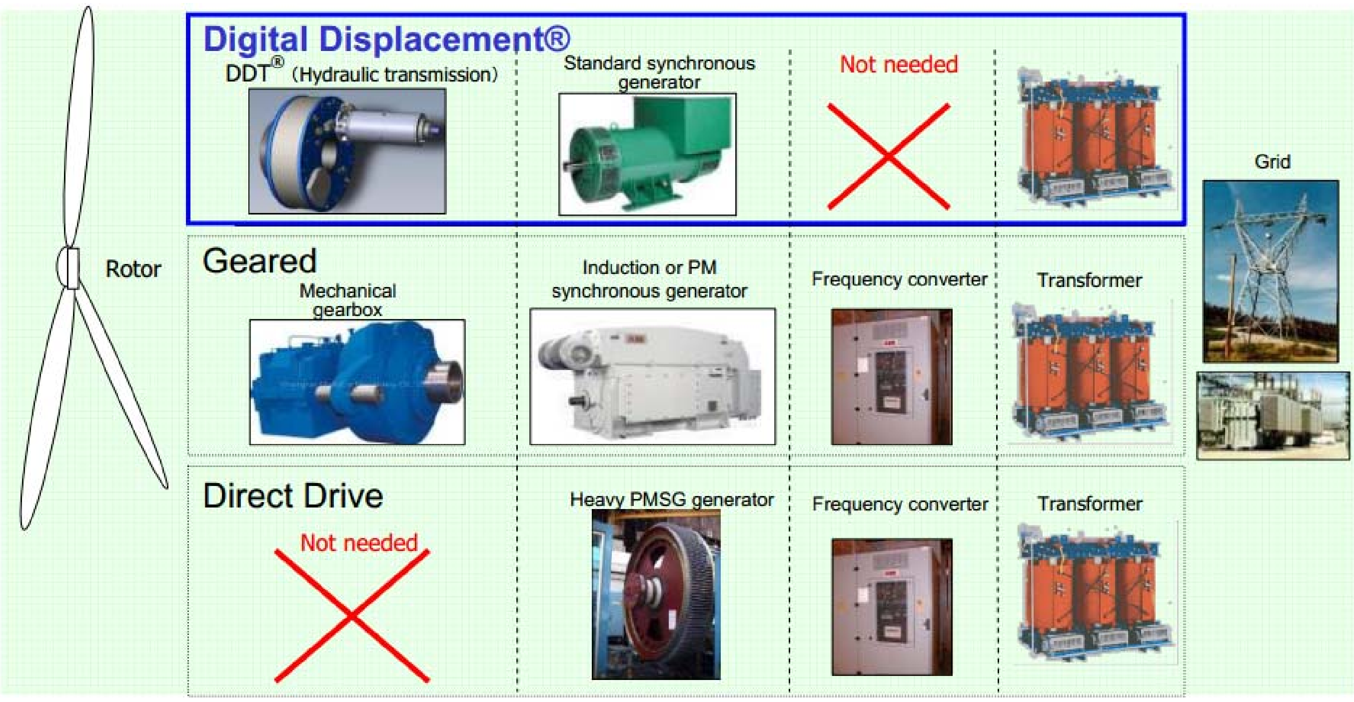
Mitsubishi is developing a potential solution to these problems through its hydraulic direct-drive technology, set to be incorporated in the 7 MW SeaAngel turbine. The digital-displacement hydraulic transmission (DDT) uses dozens of hydraulic cylinders around the main shaft to compress a hydraulic fluid (oil), which drives two hydraulic motors, each of which drives a generator. Crucially, the technology uses standard brushless synchronous generators, which do not require rare earth metals and are considerably cheaper than alternatives used in geared and conventional direct-drive turbines (Mitsubishi Heavy Industries, 2012b).

Figure 39. Hydraulic direct-drive drive train, developed for MHI 7 MW SeaAngel turbine (Mitsubishi Heavy Industries, 2012b)



The transmission is also highly efficient. The intelligent digital control allows the number of cylinders used to be adjusted in response to wind speed, enabling high energy transmission efficiency from the blades to the generator by stopping some of the cylinders when the wind is weak. By controlling the amount of pressure produced by the pumps (which rotate the hydraulic motor), this also means that the rotation speed of the generator can be finely adjusted, and therefore directly and finely adjust the voltage, frequency, and power output of the generated electricity. This ability means that power converters, which are required in conventional wind turbines, are not necessary in hydraulic wind turbines (NEDO, 2013).

Figure 40. Comparison of drive train components between different transmission types (Mitsubishi Heavy Industries, 2012b).



In combination, the lighter hydraulic transmission and standard synchronous generator, together with the absence of a power converter, results in a more lightweight nacelle. The transmission system is also low cost, with less expensive generators, no power converter, and hydraulic equipment already commercially available. In addition to lower CAPEX, the modular design is also expected to reduce operating costs. With conventional drive trains, major breakdowns can create the need to replace the entire system. With hydraulic DDT, however, it is possible to cope with such situations through partial replacement of the hydraulic components. Thus, even if one hydraulic motor breaks down, as long as the other motors are operational, output will never drop to zero (NEDO, 2013). Reducing downtime in such a way can reduce costs considerably.

Nevertheless, despite the potential benefits listed above, there are still concerns over using a hydraulic system. Namely, there is still scepticism in the industry due to the unproven nature of the technology in a turbine, in addition to the mechanical complexity and substantial use of oil. There is therefore great anticipation in the industry ahead of the first prototype installation, expected at the Fukushima floating offshore site in 2014/15. The DDT technology has already been tested in a 1.6 MW prototype in 2011, which built on earlier work supported by the Carbon Trust, and more recently in a retrofitted 2.4 MW MWT wind turbine at Mitsubishi's in-house test site in Yokohama (Artemis, 2013).

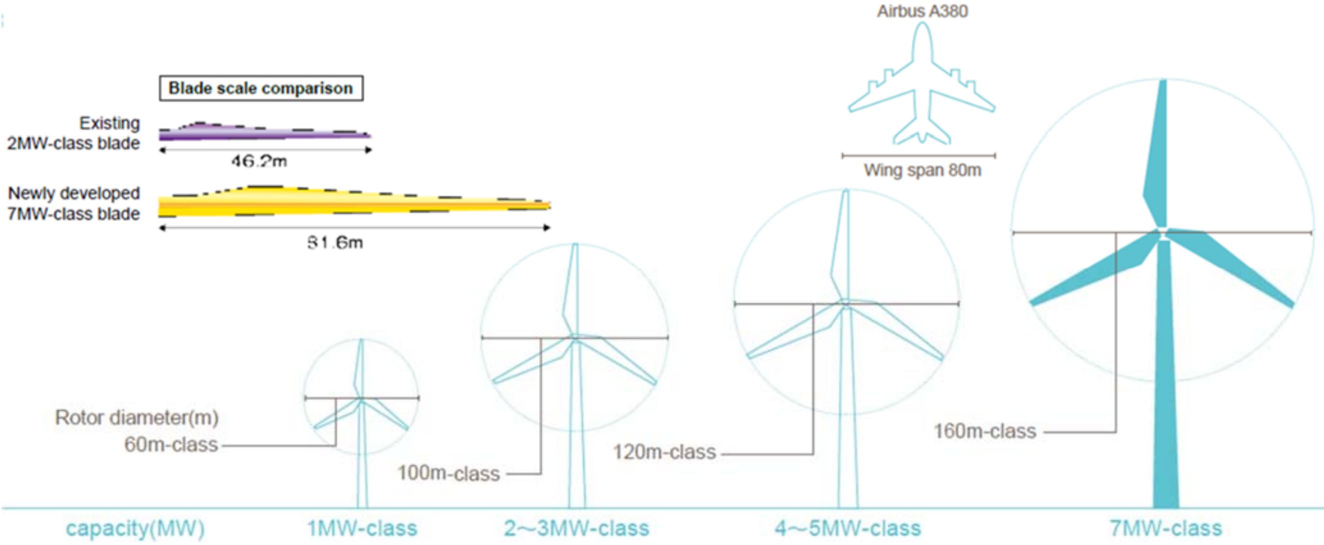
Generators

The importance of generator cost and performance has already been documented above. Particularly as manufacturers shift towards gearless, direct-drive turbines, the performance of the generator will become increasingly important. Switching to direct-drive turbines creates additional challenges for the generator due to the increased complexity of design, number of poles, and cost of the components (namely, magnets produced from rare earth metals) (LORC, 2013). While doubly-fed and permanent magnet generators are currently most common, superconducting technology is expected to improve performance in the long-term. As technology breakthroughs reduce the costs of superconducting materials, these generators are expected to increase their share of the market and improve the efficiency of generators, particularly in larger turbines, thereby increasing their cost-effectiveness.

Blades

As turbine capacity increases, so too will the blade length, which will add increasing stresses and create challenges to reduce weight, maintain strength, and minimise costs. While the average rotor diameter for 3 MW turbines is ~100 metres, this will need to increase to ~140-150 metres for 5 and 6 MW turbines, and greater yet for 10 MW turbines. Mitsubishi's 7 MW SeaAngel turbine will have rotor diameter of 165m. Reducing the load and weight of the blades will therefore be critical to ease the pressure on the tower and maximise energy conversion, whilst maintaining sufficient blade strength. Given Japan's meteorological conditions, resistance to typhoons is another vital criteria for blades. While control systems to adjust the pitch and yaw of blades can help, the integrity of the blade itself must be able to withstand significant stresses during typhoon conditions.

Figure 41. Increasing rotor diameter and blade length in line with turbine power output (NEDO, 2013)



Blades have conventionally been made from glass fibre reinforced plastic (GFRP), and all turbines currently installed in Japan have GFRP blades. However, as blade length increases the degree of bending from the wind increases beyond what the strength of GFRP blades can endure. Carbon fibre reinforced plastic (CFRP) provides significantly improved performance both in terms of weight and strength; however, at ~10 times the cost of GFRP is not cost effective in large quantities (NEDO, 2013). To compensate, blade manufacturers can use a limited amount of CFRP, targeted in parts of the blade which come under most stress. This simultaneously increases strength and reduces weight, whilst ensuring that costs are controlled. Indeed, this approach has been adopted for the 81.6m blades of MHI's 7 MW SeaAngel turbine, which are targeting over 55% carbon fibre composition, making them the longest blade with highest carbon fibre composite in the world (Mitsubishi Heavy Industries, 2012b).

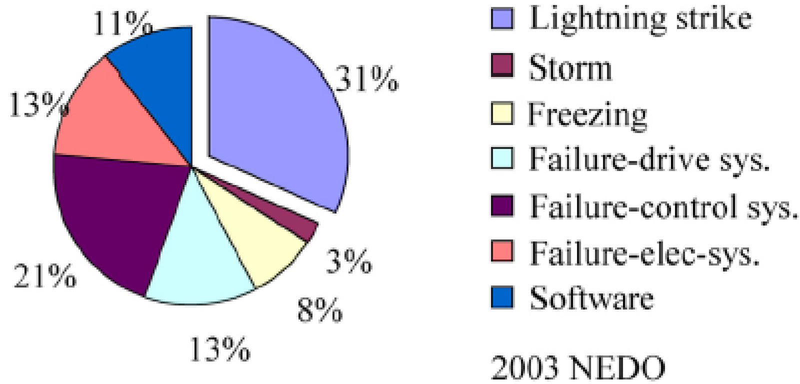
The blades are also designed to be durable and resist fatigue. The velocity at the blade tip of the 7 MW SeaAngel will reach 300 km/h, at which speed normal paint will peel off when raindrops hit the blade. Furthermore, ultraviolet radiation from being exposed to sunlight for long periods reduces the strength of the paint. The MHI SeaAngel blades have therefore undergone significant durability testing under intense UV and high-speed raindrop impact, as well as applying high-durability coatings. The blades have been both manufactured and tested in Germany (NEDO, 2013).

Typhoon resistance

Possibly the greatest threat to wind turbines in Japan is the potential damage caused by severe weather, such as typhoons and lightning storms. Japanese onshore wind farms have already suffered significant damage from storms, most notably in Miyako Island, Okinawa, in 2003, where all 7 turbines were destroyed by a typhoon, with three falling down, three losing blades, and one losing the roof of its nacelle (Figure 42) (Innovation Norway, 2013). Furthermore, a set Japan Steel Works 2 MW turbines were recently damaged by storms which hit the onshore wind farm of Tsu IV wind farm in Mie prefecture, Western Japan. Despite being designed to withstand wind speeds of 70 km/h, severe storms carrying winds of up to 150 km/h caused blades to break off a number of turbines, as well as damage to several turbine towers (Wind Power Monthly, 2013). Lightning storms also pose a considerable threat and are the most common cause of failures in Japanese wind farms (Figure 43).

Figure 42. Typhoon damage to turbines on Miyako Island, Okinawa, in 2013 (Innovation Norway, 2013)

Figure 43. Source of turbine failures in Japanese wind farms (NEDO, 2003)



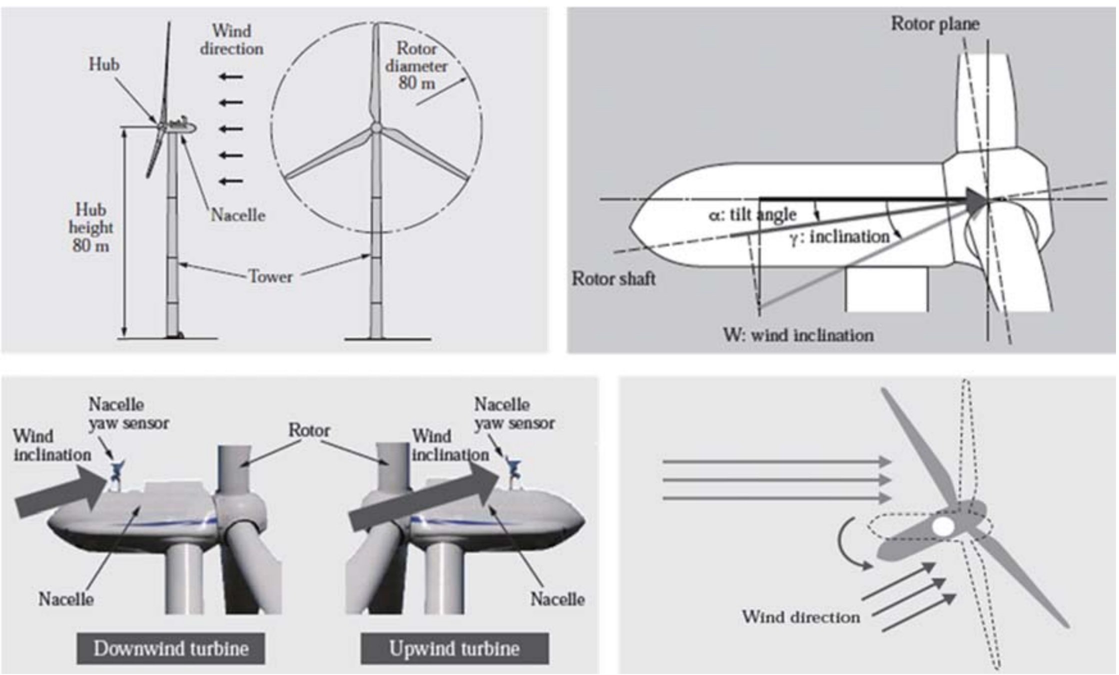
To avoid having to make over-engineered wind turbines that could all operate reliably on all sites, no matter the site characteristics, manufacturers design their wind turbines for specific 'wind classes'. IEC standards have played an important role in providing design specifications to ensure that turbines are appropriately engineered against damage from hazards within the planned lifetime, typically 20 years for wind turbines. The turbine classes are determined by three parameters - average wind speed, extreme 50-year gusts, and turbulence (how much the wind varies typically within 10 minutes). However, even the highest IEC Class I specifications are not deemed sufficient to eliminate damage in Japanese wind farms, which are subject to wind characteristics that exceed the levels classified in IEC wind turbine classes. This has prompted the introduction of a set of J-Class Wind Turbine Guidelines, a major R&D effort to ensure that turbines are suitably designed to withstand typhoons and lightning strikes. J-Class turbines are classified under the IEC S-Class, in which values are specified by the designer, and set higher specifications for the three key parameters (Matsumiya et al., 2007).

Table 12. IEC 61400 Wind Turbine Classes and Specifications

Turbine Class	IEC I High Wind	IEC II Medium Wind	IEC III Low Wind
Annual average wind speed	10 m/s	8.5 m/s	7.5 m/s
Extreme 50-year gust	70 m/s	59.5 m/s	52.5 m/s
Turbulence classes	A 18%	A 18%	A 18%
	B 16%	B 16%	B 16%

Among the design considerations for ensuring protection against typhoons is to develop downwind turbines. The downwind configuration means that blades do not need to be rigid, and can be allowed to flex in high winds without striking the turbine tower. The Hitachi 2 MW offshore turbine also has a small amount of negative tilt to maintain clearance between the rotor and tower. As this reduces the angle between the rotor shaft and wind inclination, it also increases the amount of power generated (Hitachi, 2013). The downwind orientation also limits interference between the rotor and yaw sensor, compared to upwind turbines. This is crucial to maintain accurate yaw measurements and control, particularly during turbulent wind conditions. As well as yaw control, downwind turbines offer the potential to use free yaw, in which the rotor is allowed to orient itself freely in the wind like a weathervane. This idling is particularly beneficial in strong winds, such as a typhoon, so that the nacelle can keep up with the changes in wind direction and limit the stresses on the turbine (Hitachi, 2013). The downside of a downwind orientation is the tower shadow effect, which can block wind and affect turbulence; however, these are outweighed by the benefits of downwind turbines in strong winds.

Figure 44. Top-left: Downwind configuration of 2 MW turbine; Top-right: Relationship between downwind rotor and wind inclination (power increases because of the smaller angle between the rotor shaft and wind inclination); Bottom-left: Positional relationship between wind inclination and yaw sensor; Bottom-right: Free yaw, (Hitachi, 2013)



Blade strength can be improved through the integration of carbon fibre into blade material composites, providing extra strength in areas subjected to greatest stress (as documented above). However, blades are also susceptible to lightning strikes, particularly as carbon fibre content is increased, since it is a conductor of electricity. If there is a lightning strike, the current flowing through the blade can cause a breakdown. Winter lightning strikes along the Sea of Japan have been shown to be stronger than IEC standard classes (Figure 45), and the frequency of damage from lightning strikes has caused turbine designers to apply a great focus on mitigating the problem. For example, the level of protection against lightning on the Fuji 2 MW Subaru turbine is ten times higher than stipulated in the IEC64100-24 standard for lightning protection. The blades contain conductors which run from the tip to the bottom, connected to receptors in the middle of the blades and to aluminium castings at the tip to allow lightning current to flow from the blade to the ground through slip rings which transfer the current through the rotating mechanism and act as a bypass circuit to protect the bearings (Fuji, 2007). A lightning rod is also fitted at the front of the nacelle to protect the wind sensors and ensure that the lightning flows to the tower without causing damage in the nacelle. Inside the nacelle, lightning protection zones (LPZs) and thorough shielding is used, with the nacelle acting as a Faraday cage to shield the interior from the electromagnetic radiation generated by external lightning (Fuji, 2007).

Figure 45. Comparison of IEC standard lightning characteristics and observed characteristics along the Sea of Japan during winter (Fuji, 2007)

Protention level	Peak current [kA]	Specific energy [kJ Ω^{-1}]	Average rate of current rise [kA/μs]	Total charge transfer [C]
I	200	10,000	200	300
II	150	5,600	150	225
III	100	2,500	100	150
IV				
Winter lightning*	250	150,000	32	350

*95% coverage of winter lightning

The Mitsubishi SeaAngel 7 MW turbine employs a similar defence system against lightning strikes. However, the blades of the turbine adopt a structure in which a copper mesh is attached to the blade surfaces to allow the electric current to escape. The technology has been tested by the same verification techniques used for lightning-resistant design of aircraft wings, with current flow exceeding the most sever IEC standards. The tests proved that the copper mesh can transmit the current without impacting the quality of the CFRP blades. MHI also conducted lightning receptor tests with exposure to lightning from every possible angle and achieved a 100% capture rate (NEDO, 2013).

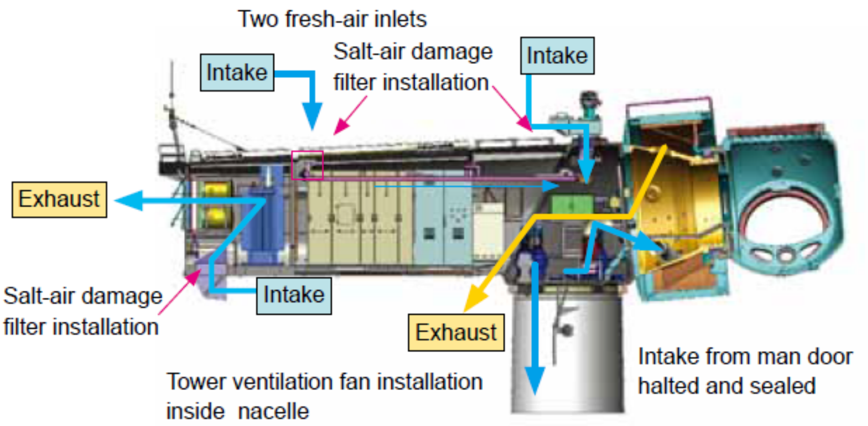
Electric & control systems

Electric and control systems are a common source of turbine failure (Figure 43). While small electric components are cheaper to repair/replace than a damaged gearbox or generator, the loss of energy production from periods of downtime can be extremely costly. Ensuring high quality and reliability in electrical systems is therefore crucial for project economics.

Corrosion

In contrast to onshore wind farms, offshore turbines are exposed to harsh marine conditions in which high salinity can lead to corrosion and component failures if it enters the nacelle. Temperature is also a threat to performance, with both overheating and freezing a challenge. As part of the Choshi and Kitakyushu demonstration projects, NEDO are helping to develop nacelle technology including salt removal filters, heat exchangers, and other salt-resistant mechanisms for reducing the flow of salt into the nacelle. To cool onshore turbines, outside air is typically taken in from the lower part of the tower and sent to the nacelle. However, such an approach in an offshore environment would result in highly saline air entering the turbine. Thus, to overcome this problem, offshore turbines will reverse the airflow and only take in air after filtering it through a salt removal filter from the upper part of the nacelle (Figure 46) (NEDO, 2013).

Figure 46. Ventilation and salt removal filter system in offshore wind turbine (NEDO, 2013)



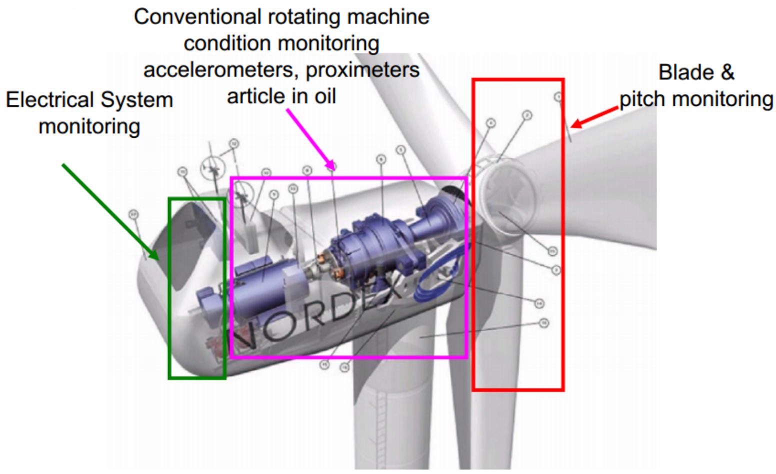
Freezing

In addition to temperature inside the nacelle, cold temperatures also pose a threat to the blades and rotor. Freezing is common, particularly in the northern regions of Japan, during winter and can result in downtime and require manual de-icing if no de-icing system is in place.

Condition Monitoring Systems

Reducing downtime is critical to project economics, particularly given the challenges of conducting repairs and maintenance offshore. The difficulty of accessing turbines in harsh conditions can mean that a failure incurred during winter may not be repaired until summer. Condition monitoring systems (CMS) are therefore vital in detecting when failures might occur, so that maintenance can be conducted in advance of failures and in batch, minimising the amount of costly unscheduled visits to the turbine. CMS typically consist of many vibratory sensors (accelerometers) located around key components in the nacelle which send data to wind farm operators at frequent intervals. Alternative CMS exist to monitor oil condition – wear counter, ferrous contents, viscosity – and rotor status – blade imbalance, ice detection, and blade damage. Data is fed in to a computer system which will alert wind farm operators when given thresholds are breached. Japanese OEMs can leverage experience from CMS installed in onshore turbines, as well as strong track record in electronics engineering to make this an area of real strength for Japanese companies.

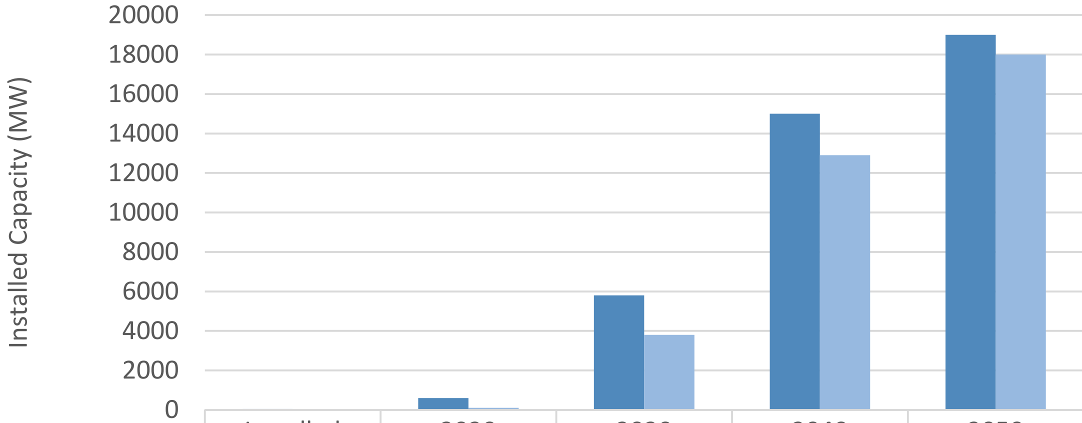
Figure 47. Condition monitoring systems in offshore turbines (SuperGen, 2007)



6.2 Foundations

Japan has plans to install 37 GW of offshore wind power by 2050, which will be provided by both floating and fixed-bottom offshore wind farms (Figure 48). Since fixed-bottom technology is currently more mature and lower cost, it is expected to dominate offshore wind installations up to 2020-2025. However, since the bathymetry of Japan's coastline favours floating installations, these are expected to experience significant growth beyond this period, as the technology is proven and developed at scale, with costs expected to fall significantly. Developing expertise in floating structures is also likely to provide export opportunities as the US and Europe begin to develop more floating projects.

Figure 48. Current and expected installations of fixed-bottom and floating offshore wind capacity in Japan up to 2050 (4coffshore, 2013) (Japanese Wind Power Association, 2014)

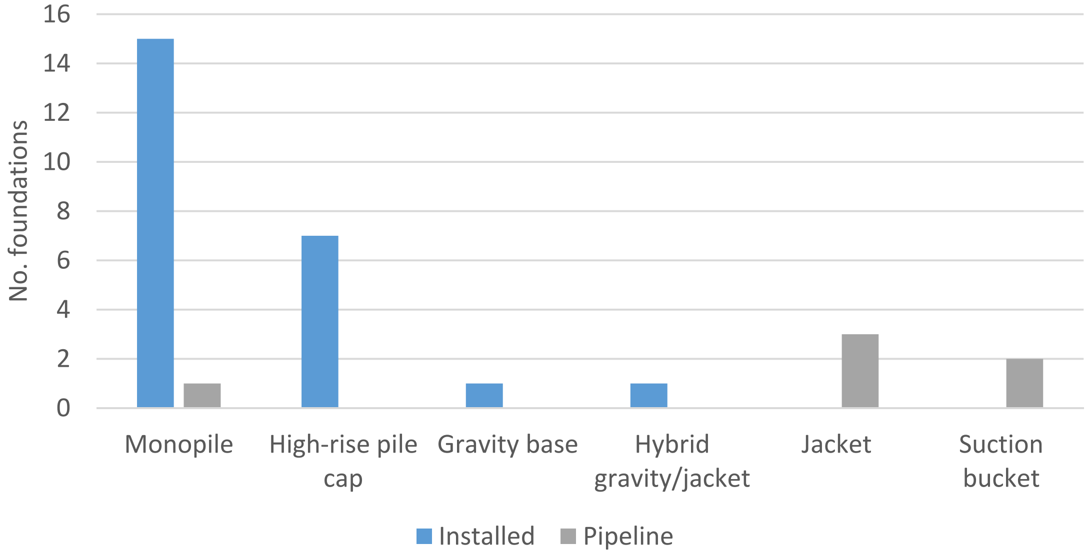


	Installed	2020	2030	2040	2050
Fixed-bottom	46	600	5800	15000	19000
Floating	4	100	3800	12900	18000

Fixed-bottom foundations

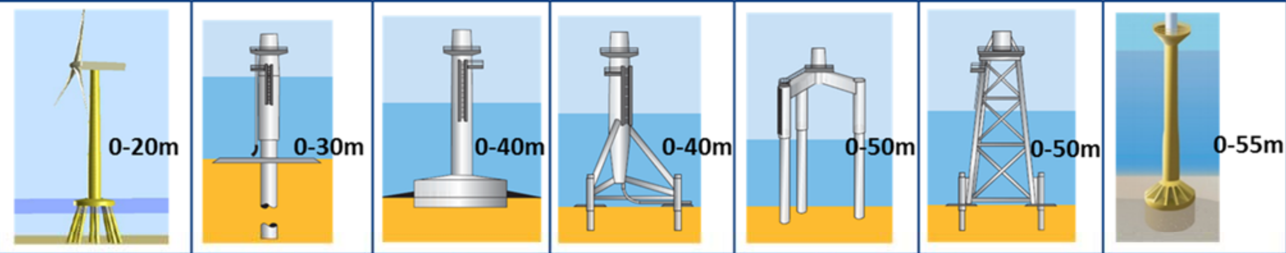
Fixed-bottom offshore wind projects are located close to shore in water depth up to 25m, largely due to the steep bathymetry of Japan's coastline. Early nearshore projects in Sakata and Setana employed high-rise pile caps, common in the onshore industry, while Kamisu nearshore wind farm used conventional monopiles for its 15 turbines. Japan's first truly offshore projects at Choshi and Kitakyushu have both opted for gravity base structures, with the latter using a hybrid gravity/jacket design. While the majority of pipeline projects are yet to reveal their choice of foundation design, there are plans for more monopiles, jackets, and suction bucket foundations (4coffshore, 2013).

Figure 49. Fixed-bottom foundation types installed and planned (4coffshore, 2013)



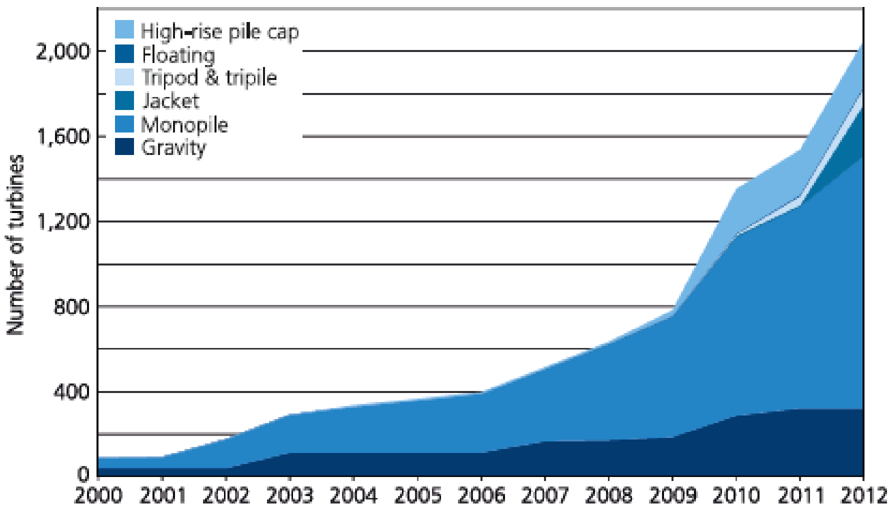
A summary of the different fixed-bottom foundation types available is shown in Figure 50. The monopile has been the foundation of choice for most projects worldwide, installed in water depth <30m. However, as offshore projects move into deeper waters further from shore, more cost-effective solutions using less steel, such as jackets and suction buckets, are expected to become more common.

Figure 50. Summary of the different fixed-bottom foundations available for offshore wind turbines (Carbon Trust, 2014)



	High-rise pile cap	Monopile	Concrete gravity base	Tripod	Tri-pile	Jacket	Suction Bucket
Design	0-20m	0-30m	0-40m	0-40m	0-50m	0-50m	0-55m
E.g.	Sakata (JP)	Kamisu (JP)	Choshi (JP)	Longyuan Rudong intertidal (CH)	Bard Off-shore 1 (DE)	Kitakyushu (JP)	Dogger Bank (UK)
Pros	Cap protects against maritime collisions	Simple design	Cheap No drilling	More stable than monopile	Can be installed by traditional jack-up barge	Stability Light	Less steel No drilling
Cons	Limited water depth Complex manufacturing	Diameter increases significantly with depth Drilling	Seabed preparation required	More complex installation	Cost	Cost	Not applicable to hard seabeds
Comments	Common in onshore industry	Most widespread foundation type Limitations in water depth	Currently only used in shallow water	High production costs due to complex structure and weight	High production costs due to complex structure and weight	Commercially attractive >35m due to their flexibility and low weight (40-50% less steel than monopiles)	Yet to be deployed at scale

Figure 51. Use of different foundation structures for offshore WTGs worldwide between 2000 and 2012 (Fraunhofer, 2012)



High-rise pile caps

High-rise pile caps consist of large concrete caps supported by 6 piles, and have traditionally been used in onshore projects. They are particularly well-suited to calm, shallow waters close to shore, as well as soft seabeds where the multi-pile structure provides good stability. Given the close proximity to shore of the nearshore projects in Sakata and Setana, high-rise pile caps were a natural choice in order to leverage existing capability of manufacturing and installing these foundations in onshore wind farms. However, in deeper waters the complex structure means that they are more difficult to fabricate and not cost-competitive with monopiles. It is therefore unlikely that high-rise pile caps will be used for future projects.

Figure 52. High-rise pile cap foundation supporting 2 MW turbine at Sataka nearshore wind farm (Wikimedia, 2005)

Monopiles

Monopiles are the most common offshore wind foundations installed worldwide, largely due to their simple design and fabrication, low cost, and well-established installation procedure. The tubular steel structure has been optimised to produce a favourable low-cost solution for most projects in water depth <25-30m. However, beyond this water depth, monopiles become less stable and also increase in cost due to the increasing amount of steel being used. Particularly as turbine capacity increases, monopiles will need to increase in diameter in order to support the larger and heavier turbines. Foundations which use less steel, such as jackets and suction buckets, are likely to be more cost-effective beyond 30m water depth.

Monopiles may also encounter stability issues in strong ocean currents, particularly as diameter increases. The Sea of Japan is known for its severe meteorological and marine conditions, and typhoons are a common threat, as well as tsunamis. The smaller surface area of jacket structures may offer greater stability under these offshore conditions. Monopiles may also be vulnerable to failure during earthquake, since they offer little flex. However, it should be noted that the 7 turbines installed on monopiles at Kamisu nearshore wind farm withstood the Great East Japan earthquake and tsunami in 2011, only shutting down temporarily when a nearby sub-station became flooded (Wind Power Monthly, 2013).

Another potential drawback of monopile foundations is the necessity for hammer piling. Hydraulic piling hammers are expensive and have to be imported if not readily available from local suppliers, and the hammer piling process means that a specially grouted transition piece must be used in order to install the turbine, which can cause additional problems. Furthermore, hammer piling is a noisy process which can impact on local marine populations, which can cause major problems with regard to consenting (see "Installation" section for more). However, despite these issues, monopiles are still an extremely cost-effective option in shallow waters and can be expected to be installed in many future nearshore projects.

Figure 53. Fuji 2 MW turbines installed on monopiles at Kamisu nearshore wind farm (New Energy News, 2011)

Gravity-base foundations

Gravity base foundations are also well-suited to nearshore and shallow waters. The base is typically constructed from concrete, offering a lower cost alternative to steel, which can be filled with ballast (e.g. sand, concrete, rock) to provide increased weight and stability upon installation. The dead load at the base removes the need for piling into the seabed, thereby eliminating the issues of piling noise and making it well suited to areas where piling is not possible, such as hard and rocky seabeds. A gravity-base monopile was used for the demonstration project at Choshi, a 10m high conical design weighing several thousand tons fabricated by Kajima Corporation and installed by Yorigami Maritime Construction Co. (Figure 54). The design is based on the GRAVITAS foundation installed at the Nysted, Denmark, and Thornton Bank, Belgium. However, this is the first application in a seismically active region (Recharge, 2014).

Like monopiles, beyond 30m depth gravity-base structures lose stability and increase in cost. Installation can also require extensive seabed preparation, such as dredging. However, concrete structure are well suited to rapid construction and can be manufactured at port, ready for installation offshore. Installation can also be simplified since gravity base foundations can be floated and towed out to sites and installed without specialist marine equipment, such as heavy lift vessels, piling hammers etc. (see "Installation" section for more). Gravity base foundations may also provide better structural integrity during earthquakes, since the base isn't piled into the ground and would allow a small degree of movement under seismic tremors. The Gravitas GBF installed at Choshi claims to be earthquake-proof (Recharge, 2014).

Figure 54. Fabrication of the gravity base foundation installed at Choshi demonstration project (TEPCO, 2014)

Jackets

While not cost competitive in shallow waters versus cheaper monopile and gravity base structures, reduced steel and good stability in deep waters makes jackets a popular foundation choice at depths >25-30m. The technology for these structures is already well developed from the oil and gas industry, and more innovative design concepts are capable of reducing costs further.

However, the complex welded structure of such foundations can make manufacturing more challenging and serial production difficult to implement. Like monopiles, jacket foundations also still require hammering piles into the seabed, which increases installation time and can cause environmental problems due to the level of noise it generates. It also requires very precise piling to ensure that they are positioned appropriately (LORC, 2013).

Given the strong marine currents and rough waters around Japan's coastline, the smaller surface area of jacket structures may prove effective in coping with these stresses, particularly given the threat of typhoons and tsunamis. A hybrid gravity-base/jacket foundation was installed for the Kitakyushu demonstration project, incorporating the benefits of each concept (Figure 55). The permeable structure of the jacket greatly reduces wave impact, while the gravity base is both easily fabricated and simplifies the installation process. Thus, while adding a concrete base to a conventional jacket might increase material costs, it will likely be compensated to an extent by the simplified and cheaper installation process.

Figure 55. Hybrid gravity/jacket foundation installed at Kitakyushu demonstration project (NEDO, 2013)

Tripods and tri-piles

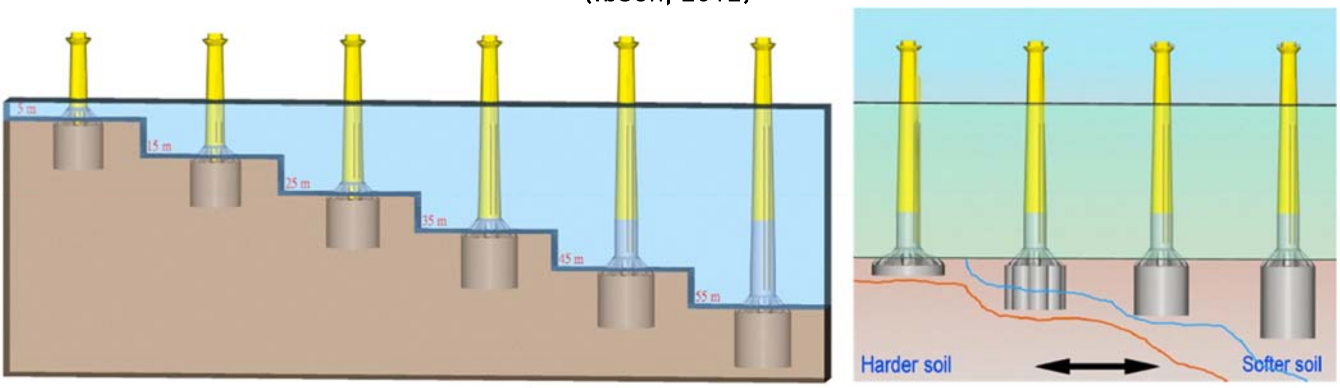
Tripods and tri-pile foundation are alternative welded structures which could be used. However, these concepts are typically higher cost than monopile, gravity base, and jacket foundations, and are rarely competitive, largely due to the increased volumes of steel used.

Suction bucket

A more novel and cheaper alternative to monopile, gravity base, and jacket foundations could be suction buckets. Suction bucket foundations use less steel than traditional monopiles and are far easier to install, since they do not require drilling or hammer piling, resulting in a 20% cost reduction compared to conventional foundations (Guardian, 2013). The absence of hammer piling also carries significant environmental benefits.

Another advantage of suction buckets is the variety of coastal conditions in which they can be installed. They can be installed in depths ranging from 0m to 55m and in variable seabed conditions, provided there are soft soils at the surface (Figure 56). There is also no need for a transition piece (and therefore grouted connections), since the upper part of the shaft can be adjusted to fit the standard wind turbine tower (Ibsen, 2012). Once installed, the structure behaves much like a gravity-base foundation, and should therefore provide good stability even in adverse meteorological and marine conditions. The bucket foundation (suction caisson) is a well-known concept from the oil and gas industry, where it has been used for more than 30 years for oil platforms installed in the North Sea.

Figure 56. Application of suction buckets in variable water depths (5-60m) and seabed conditions (Ibsen, 2012)



However, the technology has yet to be deployed at scale anywhere in the world, which may put off developers; but if more demonstration projects can verify the applicability of the technology to Japan's coastal conditions, bucket foundations could provide an attractive option. Indeed, Sasebo Heavy Industries are hoping to install two demonstration turbines with suction buckets off the coast of Ikeshima, with a view to installing a 2 MW turbine in 2015 and a 5 MW turbine in 2016 (Sasebo Heavy Industries, 2013).

Challenges

The main challenge facing fixed-bottom foundations is the choice of structure, which will need to be best suited to the site specific conditions in which they are to be installed. This will depend on the water depth, distance from shore, met-ocean conditions, geotechnical conditions, as well as the ease of installation and level of local capability to manufacture and install the foundation. Finally, the decision will ultimately be driven by cost, which will also be affected by all of the aforementioned factors. Identifying the foundations which can best meet the criteria of local conditions at lowest cost is therefore the key challenge for developers. As Japan has yet to install significant capacity, particularly in truly offshore areas, means that more demonstrations and cost benchmarking will be required in order to make this possible.

Foundations in harsh marine environments are susceptible to corrosion and fatigue. Offshore wind turbines have a typical lifetime of around 20 years, and their support structures need to survive throughout this period in difficult conditions. Corrosion affects the structure in three areas - the submerged zone, the splash zone, and the atmospheric zone. Different anti-corrosion techniques are needed to protect the structure from all threats to its integrity.

Fatigue is also an issue affecting foundations. Particularly in Japan, where strong ocean currents, typhoons, earthquakes, and tsunamis all impose stresses and loads on the substructure, the foundation needs to be designed accordingly and manufactured to high standards. The threat of structural failure from extreme weather events may also impact on foundation choice. For example, jacket structures are more permeable than monopiles and may provide more resistance to strong ocean currents. In addition, piled foundations may be more vulnerable to failure during earthquakes, since they are bound more rigidly to the seabed than alternative foundations designs, such as gravity bases.

Floating foundations

Japan has a limited number of suitable sites in sufficiently shallow water (<50m depth) for economically viable fixed foundations to be deployed, and 80% of the country's offshore wind energy resource is located in deep waters. Exploiting this wind resource would have major benefits for a country hoping to reduce its dependency on fossil fuels and nuclear power.

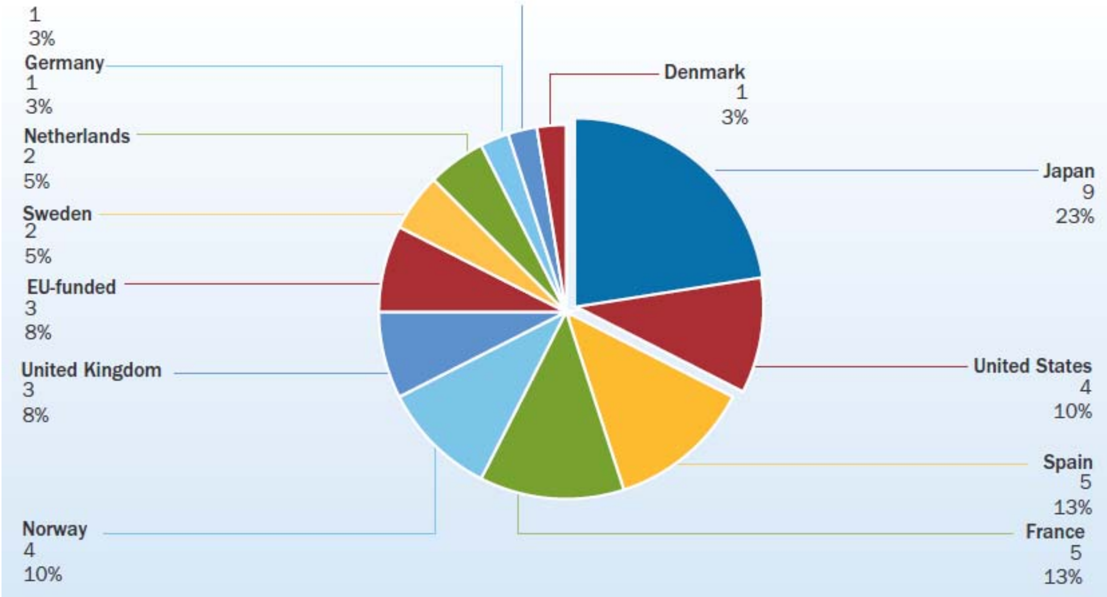
Floating foundations offer many potential benefits which alleviate some of the logistical and environmental difficulties associated with fixed foundations, including greater flexibility in construction and installation, the ability to transfer onerous bending loads onto water rather than rigid seafloor, and easier removal upon site decommissioning (EWEA, 2011). For example, while installation of fixed-bottom foundations is restricted to short seasons and limited weather windows in the hostile marine environment, floating structures can be fully assembled in a sheltered port and towed out to site. Floating turbines are also able to access the stronger, more stable, and less turbulent wind resource further offshore (GWEC, 2013).

However, floating technology has yet to be proven, and there are several technical challenges which need to be resolved, such as minimising wind and wave-induced motion; the added complexity of design; electrical infrastructure design and costs (particularly dynamic cables); and new challenges for construction, installation, and O&M procedures (EWEA, 2011).

Nevertheless, a number of countries are investing to win the race to commercialise the technology and develop floating wind turbines at scale. Indeed the prize could be significant since, with more than 70% of global offshore wind resource in deep water (EWEA, 2013b), floating foundations are tipped to be the long-term future for the offshore wind industry, and obtaining a first mover position in the market could lead to significant export opportunities.

Japan is well placed to take this lead and has over 20 years' experience of R&D in floating technology. Of the 40 floating designs under development worldwide, 9 are in Japan (EWEA, 2013b), and a number of these are expected to have full-scale demonstrations in the next few years, with potential to deploy the best concepts at scale in the 1 GW Fukushima floating offshore wind farm. However, Japan is not the only country studying the floating technology. A number of European countries are looking to trial floating turbines and the United States is also looking to tap into its significant deep water offshore wind potential (Figure 57).

Figure 57. Location of floating wind energy designs (no. projects announced) (EWEA, 2013b).



Design Concepts

Floating technology is very nascent in the offshore wind industry, and although there are various concept designs available, there is no clear winner as to which is most likely to be deployed at scale in the future. Nevertheless, there are a handful of leading concepts which have progressed beyond the prototype phase towards full scale demonstrations. The most successful can be classified into three main types of structure, which have been adapted from the oil and gas industry: spar buoy (ballast stabilised); semi-submersible platform (buoyancy stabilised); tension leg platform (TLP) (mooring line stabilised). Japanese concepts have largely focussed on spar buoy and semi-submersible structures, which underwent extensive simulation, as well as tank testing that emulated typhoon and tsunami conditions.

Figure 58. Leading concepts for offshore wind floating structures (Renewable Energy World, 2011).

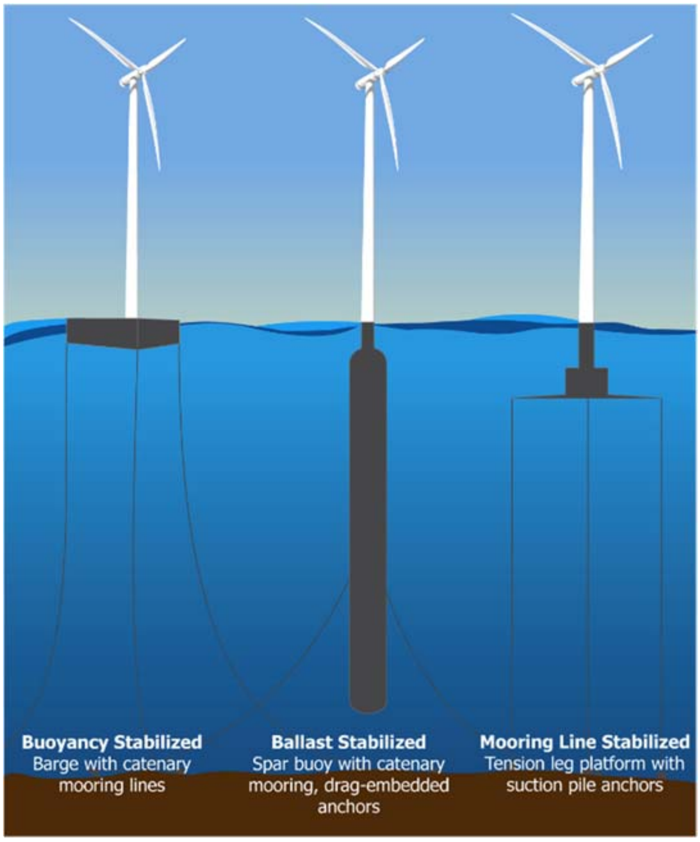
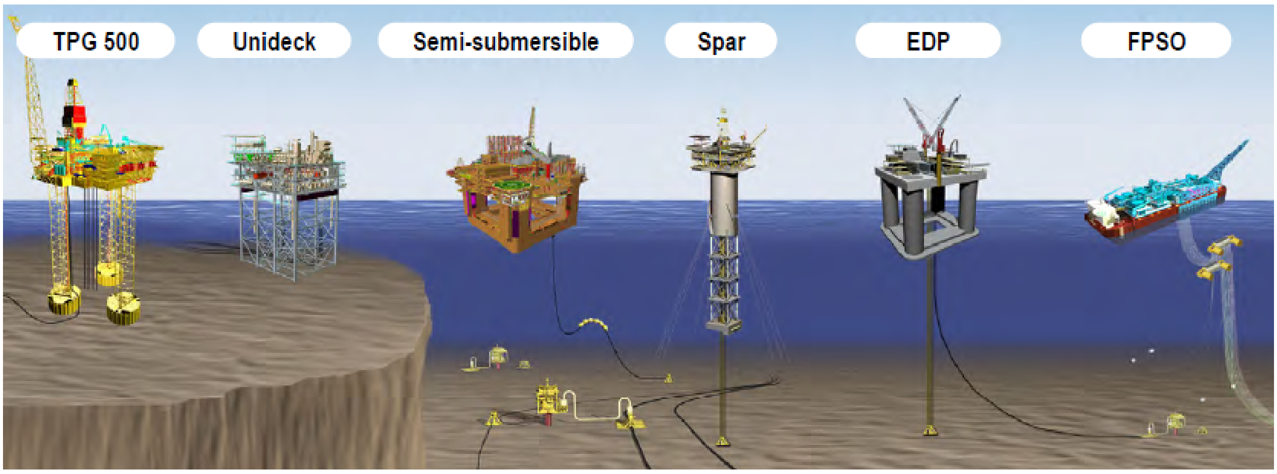


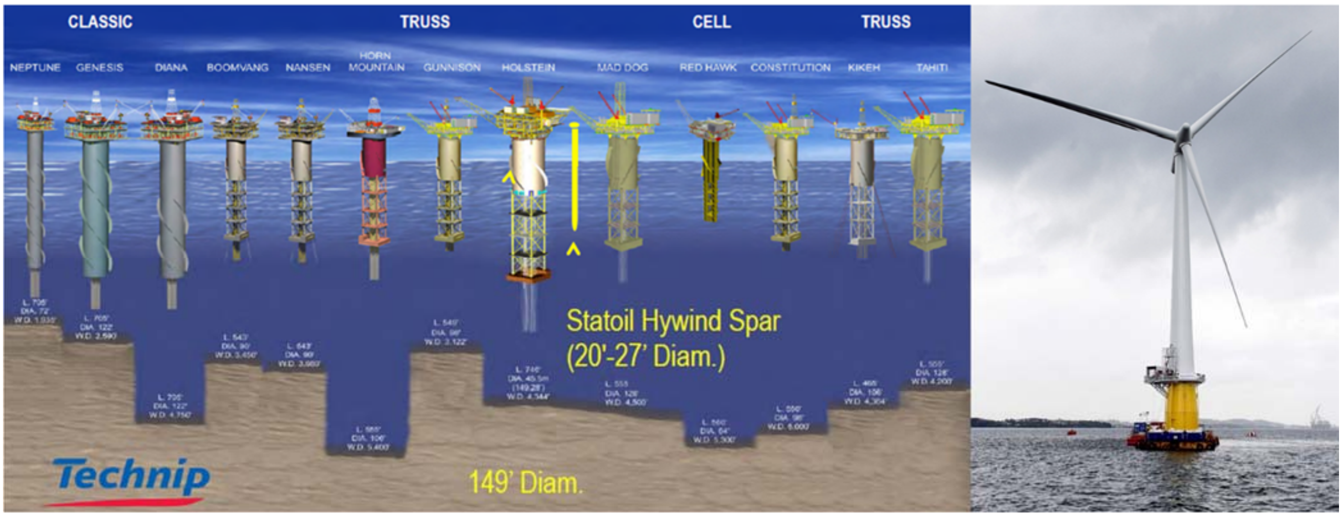
Figure 59. Floating technologies used in the oil and gas industry (Maine University, 2010).



Spar Buoy

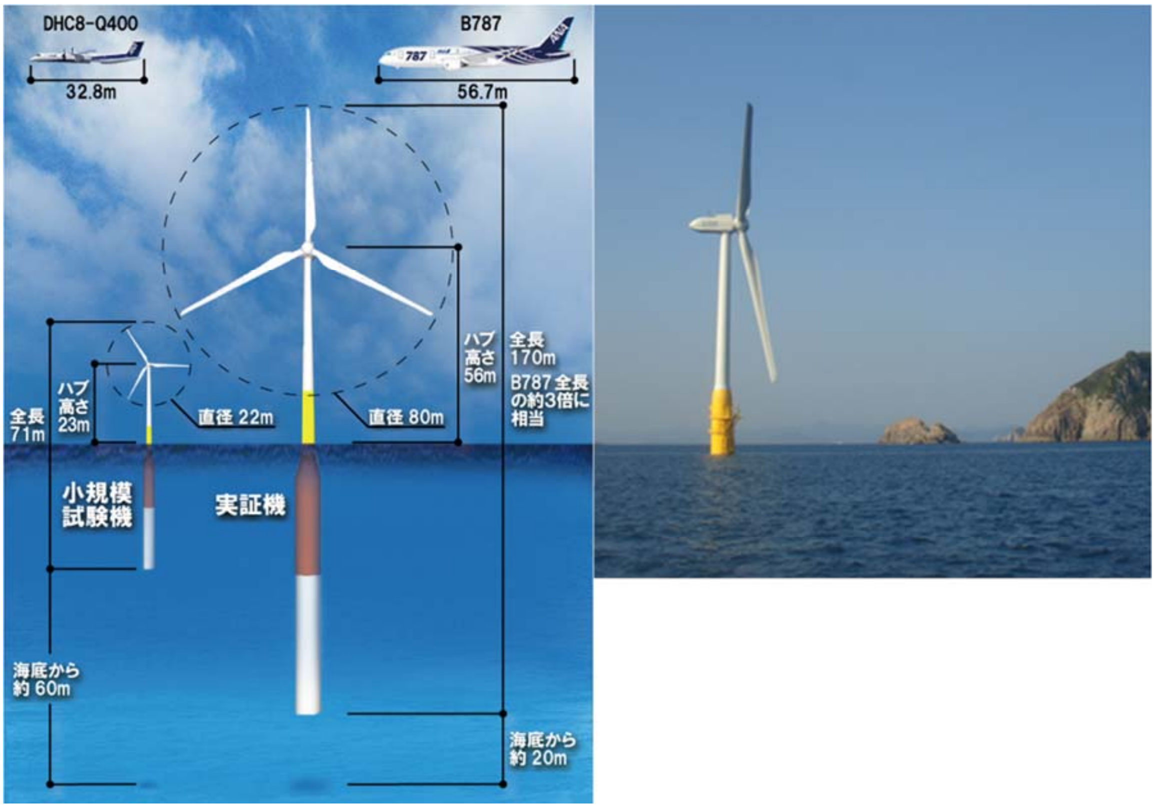
The spar buoy is a cylindrical ballast-stabilised structure. The structure gains its stability from having the centre of gravity lower in the water than the centre of buoyancy. Thus, while the lower parts of the structure are heavy, the upper parts are usually empty elements near the surface, thereby raising the centre of buoyancy. The spar buoy, a slender version of the spar buoys used in the oil and gas industry, has been a popular design concept in Japan and elsewhere. The world's first full-scale floating demonstration was the Hywind spar buoy developed by Statoil and installed off the coast of Norway in 2009. Hitachi Zosen have recently commenced a feasibility study into how the Hywind spar buoy might be deployed in Japanese waters (Wind Power Offshore, 2013).

Figure 60. Slender Hywind spar buoy compares to oil & gas spar buoy designs (Maine University, 2010); and Statoil Hywind spar buoy with Siemens 2.3 MW turbine (Statoil, 2009).



Spar buoy concepts which have also been developed in Japan. The first spar buoy installed in Japan was a 100kW prototype, located off Kabashima Island, near Nagasaki, which was scaled up in 2013 to a full-scale 170m high structure supporting a 2 MW Hitachi turbine. The bottom of the spar uses a 'super hybrid' concrete developed by Kyoto University and Toda Construction, which adds weight at the base of the structure to lower the centre of gravity. Concrete is also cheaper than steel.

Figure 61. Kabashima Goto Fowt Spar Buoy - scale-up from 100 kW prototype to 2 MW demonstration (Goto Fowt, 2014); and image of turbine and spar buoy in operation (GWEC, 2013).

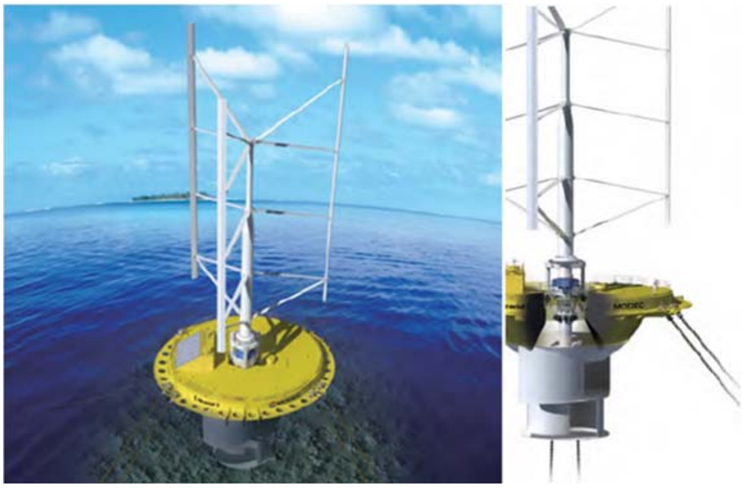


Japan Marine United have developed an 'Advanced Spar', which was used to install the offshore substation for the Fukushima FORWARD project. There are also plans to use the foundation with a 7 MW Mitsubishi SeaAngel turbine in the next phase of the project. The design includes reduced vacillation fins to minimise impact from sway and heaves (Maine International Consulting, 2013). The spar has performed well so far and survived a recent typhoon with no structural damage (University of Tokyo, 2014).

Figure 62. Japan Marine United's Advanced Spar with substation at Fukushima (Fukushima FORWARD, 2013)

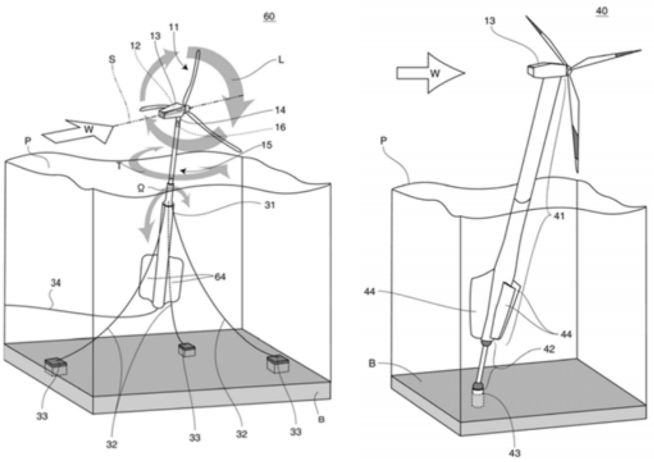
An alternative ballast-stabilised concept has been designed by MODEC (Mitsui Ocean Development & Engineering Company), who have developed a combined wind and wave power generator, aka "SKWID" (Savonius Keel & Wind Turbine Darrieus). The structure supports a 500kW vertical-axis wind turbine and is stabilised by the ballast from the weight of the marine current turbines underneath, which lowers the centre of gravity. A demonstration was due to be launched off Saga Prefecture in 2013, but a vital component sank during installation (Wind Power Monthly, 2013b)

Figure 63. MODEC SKWID ballast-stabilised design (Maine International Consulting, 2013)



R&D is also being conducted into a floating spar buoy concept by the National Maritime Research Institute. The institute has conducted significant research in to floating marine structures, including offshore wind, and is currently focussing on a floating spar design. The concept is being tested at its own deep water wind and wave tank, but is still a few years off being deployed at full-scale (Maine International Consulting, 2013).

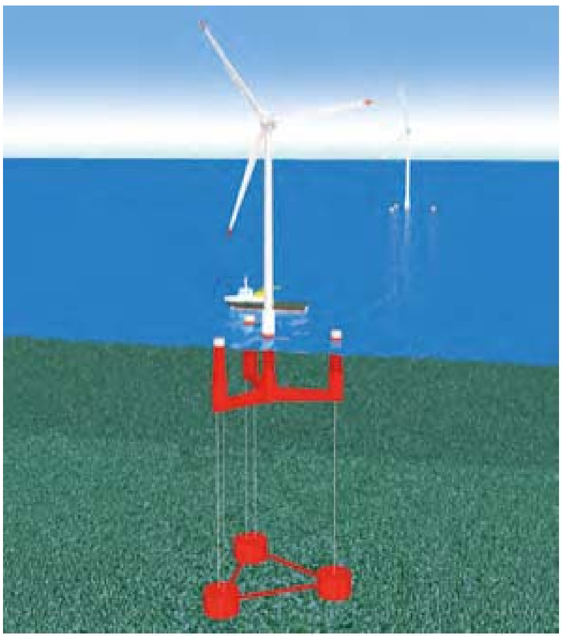
Figure 64. Floating spar buoy being develop by the National Maritime Research Institute (Maine International Consulting, 2013).



Tension Leg Platform (TLP)

The tension leg platform is a semi-submerged buoyant structure, anchored to the seabed with tensioned mooring lines, which provide buoyancy and stability. TLP designs are considered more expensive than other concepts (Sizuki, 2014), and there are currently no full-scale demonstrations in Japan. There are also concerns regarding the impact of earthquakes on the moorings. However, Mitsui Zosen has been developing a TLP design in cooperation with Tokyo University, Shimizu Corporation, Maritime Research Institute of Japan, and Tokyo Electric Power Company (Figure 65) (Maine International Consulting, 2013). The platform provides buoyancy, which is held semi-submerged under water by tensioned mooring lines that connect the platform to a counterweight lying on the seabed.

Figure 65. Mitsui Zosen tension leg platform (TLP) design (Maine International Consulting, 2013).



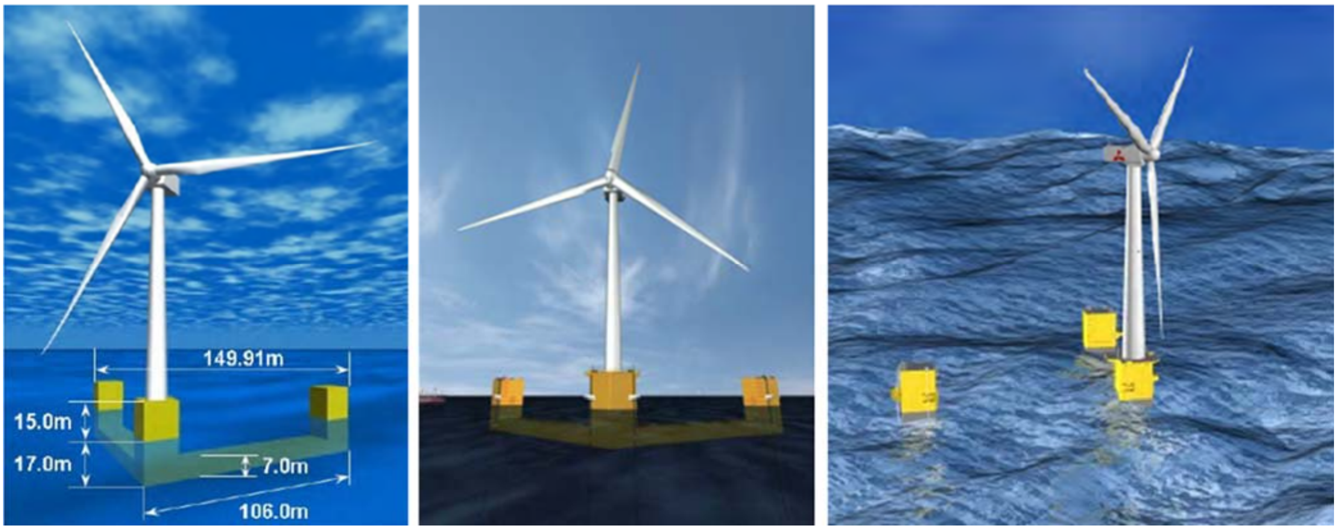
Semi-Submersible Platform

Semi-submersible platforms combine the main principles of the two previous designs with a wide and deep semi-submerged structure held by mooring lines. Japan deployed its first full-scale semi-submersible platform as part of the Fukushima demonstration projects, with the semi-sub supporting a 2 MW Hitachi turbine. The structure, developed by Mitsui Zosen, consists of 4 columns, with the turbine positioned on the central column. The semi-sub has a compact structure and has been designed to minimise floater motion through optimised ballast control. The structure has performed well with good load factor so far, surviving a recent typhoon with only minor damages to turbine sensor equipment (University of Tokyo, 2014).

Figure 66. Mitsui Zosen 4 Column Semi-Sub, installed with 2 MW Hitachi Turbine in Fukushima demonstration project (Fukushima FORWARD, 2013).

Mitsubishi are also currently developing a semi-submersible foundation. The V-shaped 3 column semi-sub is due to support the 7 MW SeaAngel turbine in the next phase of the Fukushima FORWARD project, planned for 2014/15.

Figure 67. Mitsubishi Heavy Industries 3 Column V-Shaped Semi-Sub (Maine International Consulting, 2013).



There is also a series of alternative floating semi-sub concepts being developed in Japan, including WindLens, Shimizu semi-sub, and Hitachi Zosen semi-sub designs. The WindLens floater, developed by Kyushu University, consists of a series of hexagonal platforms each supporting two WindLens turbines and covered in solar PV panels. A prototype model with two 3kW turbines was launched in December 2011 for a one year trial and a larger model with 250kW and 300kW turbines is currently under development. Shimizu Corporation, in partnership with the University of Tokyo, TEPCO, and Penta-Ocean Construction, has released designs for a novel semi-submersible structure supporting three conventional turbines; however, it is unclear whether prototype tests are planned at this stage. Finally, Hitachi Zosen have undertaken some early work into an alternative semi-submersible design; however, it is expected that Hitachi will focus on developing spar buoy structures, off the back of their partnership agreement with Statoil, who developed the Hywind demonstration (Maine International Consulting, 2013).

Figure 68. WindLens (L) and Shimizu (R) semi-submersible designs (Maine International Consulting, 2013).

Standards

If any clearer indication were required that floating wind turbine technology is rapidly maturing, DNV KEMA recently released its new standard for such structures. This follows the September 2011 launch of a Joint Industry Project (JIP) focused on floater-specific design issues, such as station keeping, site conditions in relation to low frequency motion, simulation periods, higher order responses and design of structural components. DNV KEMA has been joined on the project by the likes of Statoil, Nippon Steel & Sumitomo Metal Corporation, Gamesa, Iberdrola, Alstom Wind, Glosten Associates and Principle Power (Renewable Energy World, 2013).

However, given that most of the technologies have yet to be proven, and many of the technical challenges and solutions are only just being identified, there is still scope for more ongoing work to standardise relevant components. Indeed, the Japanese government's latest five-year ocean policy, released in May 2013, lists the development of such standards, as well as international adoption, as key requirements for offshore wind to succeed in Japan. The Japanese government is therefore also investing in a study of what standards are needed to ensure safety for maritime vessels navigating around floating offshore wind farms (Wind Power Offshore, 2013b).

Challenges

While some of the technical challenges facing floating technology may be the same or not necessarily be any bigger than fixed-bottom foundations, the designs are in their infancy and require ongoing support to prove the technologies and begin to scale-up deployment. Among the challenges is the lack of demonstrations to date, which means that suitable modelling tools are yet to be developed and verified against real data. In particular, modelling tools need to be able to simulate the whole structure's behaviour, including the interactions between the turbine, foundation, and moorings.

Linked to this, turbines will need to be optimised in design and size for floating application. To date, conventional turbines have typically been installed on floating structures; however, there will be scope to develop turbines which optimise the whole structure's architecture. New, lighter materials could also be developed to reduce the weight of the turbine, and appropriate control systems will need to be developed to stabilise the structure, enhance energy production, and minimise loads and losses (EWEA, 2013b).

Mooring and anchoring systems have emerged as a critical issue. The moorings of floating structures are subjected to significant stresses, and need to be able to extreme weather events such as typhoons and tsunamis. Moorings have already proved problematic in the Fukushima project, where the first mooring chains installed to anchor the semi-sub to the seabed proved to be too weak and broke several times. This delayed the project, extending the entire mooring process from two weeks to two months (Recharge, 2014).

Another major problem is corrosion and fatigue to the mooring chains, which would need to be replaced after 10 years of operation (Recharge, 2014). This would add significant costs which would undermine the commercial viability of floating turbines. There is therefore a specific need to develop mooring chains which can either be repaired at site or survive for the 20-year lifetime of the turbine.

Grid connection will pose similar challenges to fixed-bottom turbines but particularly significant for floating turbines will be developing suitable dynamic cables that can withstand wave movement. While fixed foundations tend to use j-tubes to protect cables, floating structures will need to employ free-hanging cables which expose the cables to more loads and stresses. Cost-effective dynamic cables will therefore need to be developed.

Wake effects modelling will also become increasingly important as farm size increases. While software has been developed for fixed-bottom wind farms, floating foundations will move position relative to one another, making wake effects modelling more challenging. Furthermore, any modelling tools will need to be verified against real data, which is currently not possibly. Demonstrations consisting of an increasing number of turbines will be needed, scaling up progressively from single prototypes to demonstration farms and pre-series production.

6.3 Installation

Fixed-bottom foundation installation

The method of installation is entirely dependent on the foundation design. While gravity base structures will require seabed preparation, foundations with piles (monopile, multi-pile, tripod, and jacket) will require hammer piling, and suction buckets will have their own unique method of installation. A particular issue for installing foundations and turbines in Japan is the rough sea conditions, which proved a major challenge in the Choshi and Kitakyushu demonstration projects. Installation is most favourable in the summer, from June to August, with high winds and choppy seas in winter causing difficulties and the typhoon season from September to November an obvious period when accessibility is low.

Piled foundations

Monopiles, multi-piles, tripods, and jackets all need piles to be hammered in to the seabed. This requires a powerful hydraulic piling hammer which can accurately maintain the vertical alignment of the foundation as it is piled in to the ground. The larger the pile, the more powerful the hammer must be; thus, monopiles require larger hammers than jackets, which typically use smaller pin-piles.

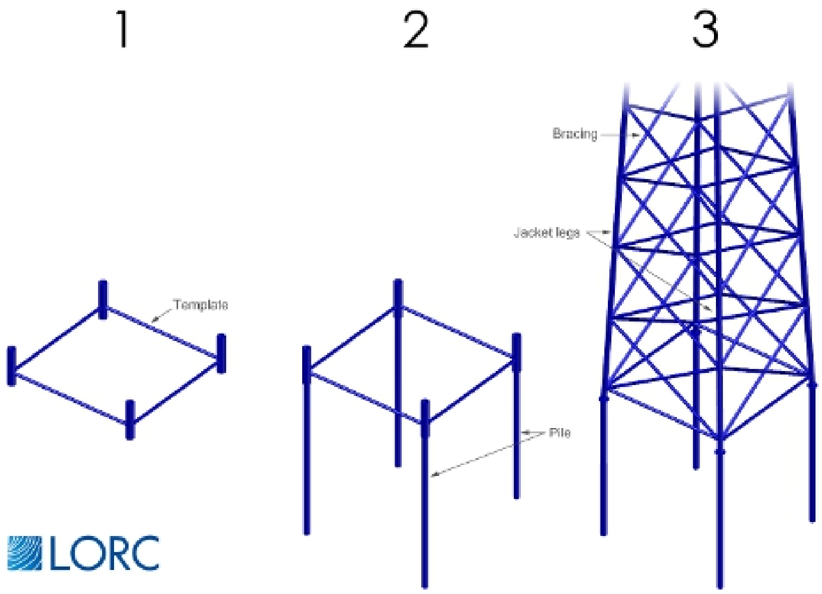
Large piling hammers were used to install the monopile foundations used in the Kamisu nearshore project (Figure 69). The piling hammer used was an IHC Hydrohammer imported from IHC Merwede and leased by Moricho Corporation (Moricho, 2010). However, hydraulic piling hammers are in limited supply in Japan, and more will need to be developed locally or imported if monopiles are to be installed at scale.

Figure 69. Piling hammer installing a monopile foundation at Kamisu nearshore wind farm (Moricho, 2010).

One of the major drawbacks of hammer piling is the noise generated, which can impact on nearby marine life. This can cause major issues when attempting to pass environmental audits and gain consenting rights, particularly in areas near to marine conservation zones and designated fishing zones. The latter is particularly significant in Japan and likely to be a potential barrier against using piled foundations.

Piling for jacket foundations is usually quieter than monopiles (though still an issue), but there is added complexity in terms of positioning the pin-piles accurately and conducting thorough seabed preparation. Jacket foundations are typically installed via the pre-piling method, in which a base template is used to drive the piles at an accurate distance from each other, before the main jacket structure is installed. Only after the piling process has been completed is the jacket lowered to the sea floor, where spikes at the end of its legs fit into the piles (Figure 70). This is in contrast to post-piling, whereby piles are driven into the sleeves at the bottom of the jacket legs. While this method is common in the oil and gas industry, it is rarely used for offshore wind installations as it is slower and therefore less efficient than pre-piling for the repeated installations required in a wind farm. Pre-piling is quicker because smaller vessels can be used for the piling, and large vessels can be used efficiently to install the jacket, which can be done relatively quickly once the piles are in place. With post-piling, the expensive large vessels have to spend more time with each jacket (LORC, 2013).

Figure 70. Pre-piling method for installation of jacket structures (LORC, 2013)



The added complexity of installing jackets means that thorough seabed preparation is necessary to ensure that the template is laid accurately. The jacket has to be level within the standard margins of 0.5 degrees. Usually, a Remotely Operated Vehicle (ROV) is used to measure the height of the piles when they have been installed with the template. The jacket (with the transition piece already mounted) is then placed on the piles, using a vessel with a heavy lift crane (LORC, 2013). An alternative approach to mitigate this complexity is to use a gravity base at bottom of the jacket, as in the Kitakyushu demonstration project.

Gravity base

For gravity bases, thorough preparation of the seabed is necessary. Comprehensive dredging of the sea floor is followed by levelling a layer of gravel and concrete, before the structure can be lowered in to place. Typically, the foundation is transported on a barge and lifted in place using a heavy-lifting crane. The weight of the structure tends to necessitate a fairly large vessel. However, an alternative solution to remove the need for such equipment is to use a self-floating gravity structure, which can be tugged to the site using simple barges. Upon installation, ballast is either pumped in to or layered around the base in order to increase its weight and improve its stability. Finally, scour protection is applied around the base in order to avoid soil erosion. While they can be floated out offshore, the greater the water depth, the greater the mass of the base must be, which makes transportation and installation more difficult in deeper waters (LORC, 2013).

Japan's only truly offshore projects have both been installed with gravity base foundations. As Japan's first offshore installations, this was very much a trial and error process, with every step a first for the industry. With no prior installation experience, work normally requiring 1-2 months took between 7-10 months. Delays were also largely attributed to the difficult meteorological and marine conditions in both locations.

The waters off Choshi are known for strong waves and currents from the intersection of the Oyashio and Kuroshio currents, and the work needed to be completed before the typhoons season of June-August. However, having started dredging the seafloor in February, the site was struck by the Great East Japan Earthquake and Tsunami the following month. Kahsima Port, where the foundation was being constructed, was also damaged. This set construction back by 1 year, with dredging resuming in February 2012. After dredging, a layer of rock was laid to level the seabed surface. However, more problems were encountered here. Despite attempting to use a mechanical underwater backhoe, poor visibility of only 30cm due to the turbulent ocean conditions meant that the work had to undertaken manually by divers. This was both more time consuming, expensive, and a health and safety risk, with divers commenting that they had never experienced such a harsh work site (NEDO, 2013). While the ground levelling was ultimately successful, with precision ±5cm attained, this demonstrates the challenge of offshore installation in Japanese waters.

Installation of the gravity base foundation was also challenging, since the weight of the foundation (2,300 tons) exceeded the capacity of the crane barge (1,600 tons), despite being among the largest class available in Japan. A lack of appropriate vessels is therefore an obvious issue for offshore wind development in Japan (see section on "Installation Vessels" for more). In the case of Choshi, the problem was overcome by semi-submerging the foundation, so that the buoyancy could offset some of the weight. Difficult weather conditions meant that installers had to wait for the optimum weather window (decreased wave height) before proceeding with the installation. Upon installation, the gravity base was filled with ballast, with a completed weight of 5,400 tons (NEDO, 2013).

Figure 71. Installation of gravity-base foundation at Choshi (TEPCO, 2014)

Installation at Kitakyushu experienced similar challenges, with unseasonable typhoons and rough waters causing delays. However, for foundation installation, lessons were learned from Choshi and a larger 4,000 ton floating crane was used to install the structure.

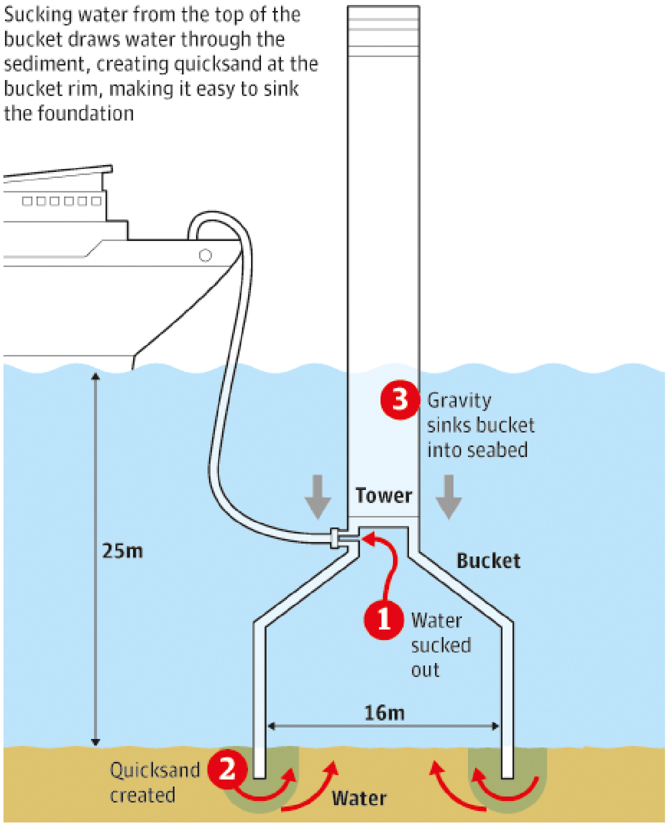
Figure 72. Installation of hybrid gravity/jacket structure in Kitakyushu (NEDO, 2013)

Suction bucket

Like gravity structures, a major advantage of suction buckets is that they do not require hammer piling. This eliminates the cost of purchasing a piling hammer as well as the environmental problems associated with hammer piling. No hammer piling also means that a transition piece is not required, since it can be built directly on to the top of the support structure, secured with bolts rather than grouting (LORC, 2013). Furthermore, and an advantage over gravity structures, no seabed preparation is required, making installation quicker and lower cost.

The light weight of the structure means that large jack-up vessels and cranes are not required. In European demonstration projects the suction bucket has been towed out to sea with barges mounted with simple cranes to hoist the structure in to an upright position before sinking to the seabed. Once here, water is sucked out of the bucket using a mechanism on board the vessel, which creates a vacuum, forming quicksand around the rim of the skirt, which allows the bucket to sink deeper in to the sea bed (Figure 73). The skirt is also fitted with nozzles which allow the bucket to be steered in to place, maintaining its vertical alignment. However, suction buckets can only be installed in soft, residual soils, and is therefore not applicable to hard sea floors, where piling is necessary to hammer through the seabed.

Figure 73. Suction bucket installation (Guardian, 2013)



Turbine installation

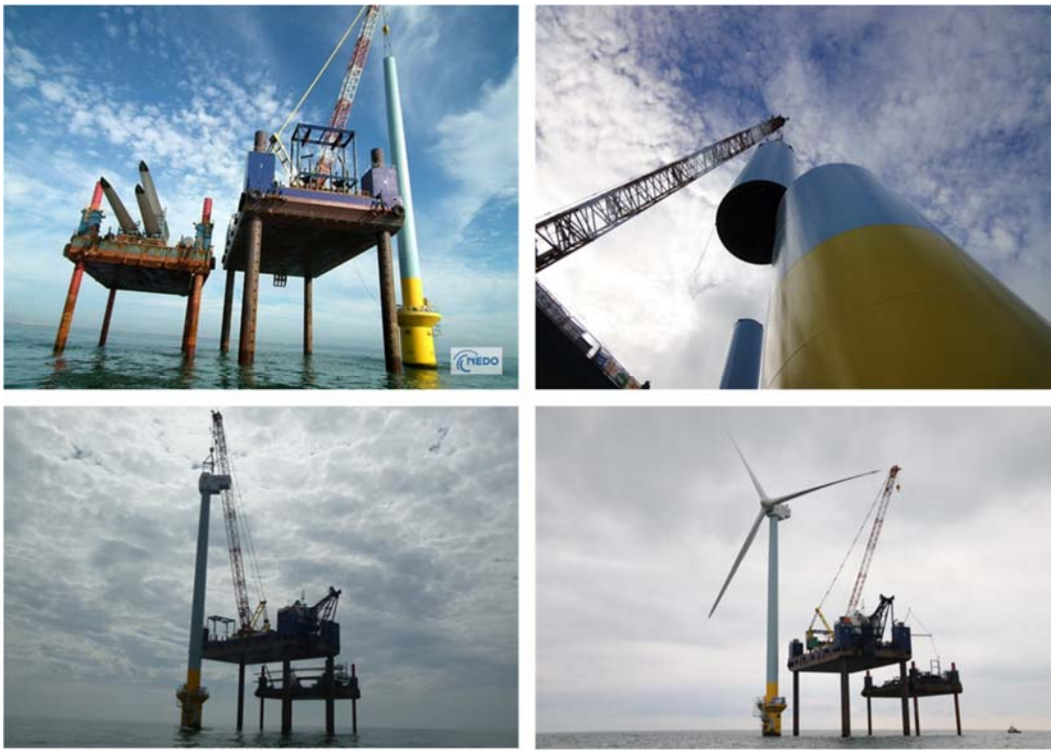
There are two ways to install wind turbines, assemble at port or on site. This is usually determined by the type of foundation and the installation company's vessel size/type, equipment, and capabilities.

- **Assemble at port:** While this can reduce installation time, and thereby reduce costs, it requires large bespoke installation vessels and cranes, which will become more acute as turbine size increases. This method also requires extremely calm weather conditions, and many early European projects using this method experienced long delays as a result of this.
- **Assemble offshore:** The process of assembling the turbine at sea takes longer, but can be conducted with smaller vessels and cranes than those used to install pre-assembled turbine units. The degree of assembly offshore is affected by the decision to either install full rotors (with blades already attached) or single blades (blade-by-blade).

Maximising the number of days when installation can take place is crucial to reducing project costs, particularly given that there is usually only an installation weather window for a limited number of days per year, when met-ocean conditions are calmer. For example, availability is typically reduced by 50-60% in winter and 25-30% in summer. For fixed-bottom turbines, experience from Europe suggests that offshore assembly can be conducted more frequently throughout the year, and is therefore preferable to onshore assembly, which has more limited installation availability. Conversely, for fully integrated float-out structures, such as floating turbines, onshore assembly at port is far more effective. This approach has been replicated in Japan, with both fixed-bottom demonstration projects opting to assemble turbines offshore, and both floating demonstrations being assembled at port before being floated out for installation.

At Choshi and Kitakyushu, self-elevating platforms (SEPs) were used to limit the impact of the strong currents and waves. The nacelle, tower, and blades are all loaded onto the SEP barge, which jacks-up to provide a stable platform from which to install each component with a heavy-lift crane (Figure 74).

Figure 74. Offshore assembly of 2.4 MW Mitsubishi turbine at Choshi demonstration project (JFS, 2013) (TEPCO, 2014)

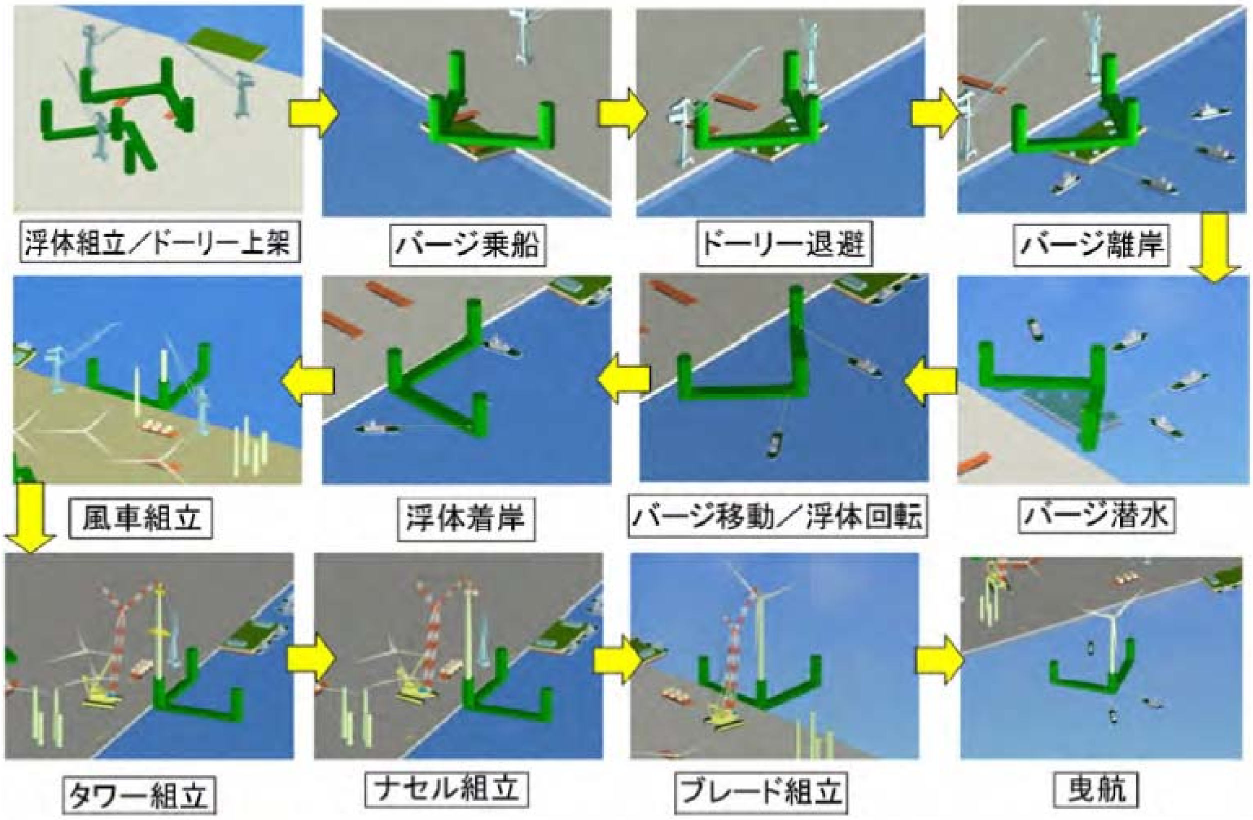


High wind speed made offshore assembly challenging and the impact of wave height was a more significant issue for transporting workers on to the turbine, since there are no bespoke access vessels and transfer systems in Japan (see "O&M " section for more on access vessels and transfer systems). Accurate forecasts of wave height and wind speed were therefore crucial in determining the viability of conducting installation on a daily basis. However, more innovative installation and assembly methods can be adopted to optimise installation processes, and thereby improve cost-efficiency and installation rates.

Floating foundation installation

Installation of floating structures is expected to be significantly cheaper than fixed foundations. While fixed foundations require heavy lift barges and jack-up vessels, floating turbines can be erected in the harbour and towed to site using standard tug boats (Figure 75). Assembling the turbine at port also means that installation is less sensitive to weather conditions, increasing installation availability and minimising delays. Furthermore, while fixed-bottom foundations tend to require noisy hammer piling and/or seabed preparation, no piling or seabed preparation is usually required for floating devices.

Figure 75. Conceptual installation of Mitsubishi Heavy Industries 3-column semi-submersible platform (Maine International Consulting, 2013)



However, floating structures do require large set down areas at port, which can be both difficult to obtain and expensive. Spar buoys also cause installation challenges due to their large hull, which requires a deep draft to up-end. This prevents them from being floated out to site directly from port, and instead requires a barge to transport the structure offshore until it reaches sufficiently deep water. This is in contrast to semi-submersible structures which require significantly less draft and can be fully assembled in a sheltered harbour before being wet-towed to its final installation site. TLP structures can also be floated to site, but installation typically requires significant seabed preparation, which may increase costs (ASME, 2011).

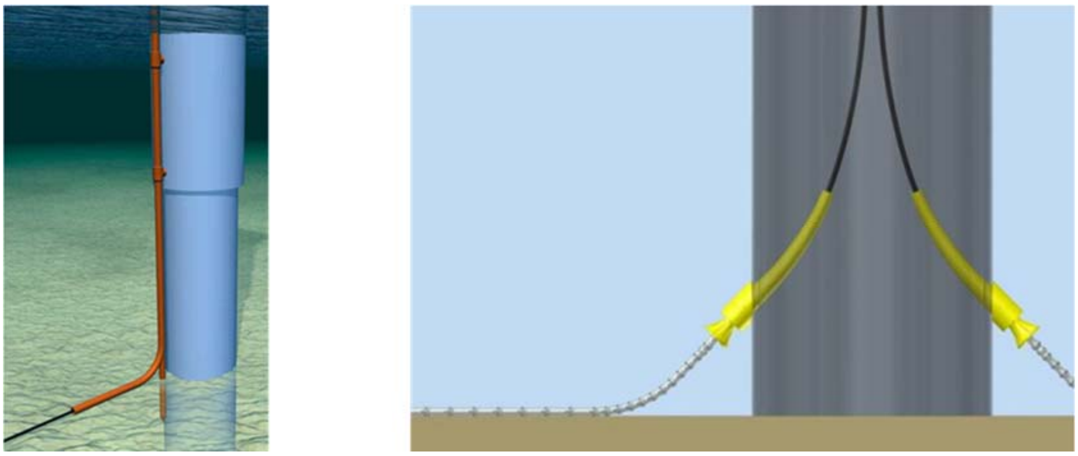
Cable Installation

Cable damage is a major risk for offshore wind projects, with ~90% of the total number of insurance claims and ~70% of the total value of insurance claims in the industry cable related (Marsh, 2012). Approximately 70% of cable failures are due to human activity (e.g. fishing lines, anchors) (GL Garrad Hassan, 2013), so ensuring that cables are adequately protected is vital in order to mitigate these risks. Burial of the cables therefore provides the best protection. Cables are traditionally buried underground using specialised installation equipment which digs a trench in the seabed, lays the cables in place, and re-lays the bed material to provide protection. While this is more expensive than leaving cables to rest on the seabed, it is a worthwhile investment in order to minimise the significant risks of damaging the cables. However, while

European standards require at least 3m burial depth, Japanese offshore projects may be able to bury cables at shallower depths, which would reduce installation costs.

Cables are also susceptible to damage during the installation process. In fixed-bottom offshore wind projects a J-tube cable entry system is traditionally used (Figure 76), which has been adopted from the oil and gas industry. However, there are alternative solutions emerging in the offshore wind market which can reduce the use of steel tubing and improve the cable installation process; namely, J-tubeless cable entry systems, in which the cables are fed through the support structure (e.g. monopile). This reduces the risk of damage from oversized pulling force during burying and cracks due to pulling in J-tubes, whilst also reducing the time and cost of cable installation (Carbon Trust, 2013b).

Figure 76. Left: J-tube cable entry system; Right: J-tubeless cable entry system (Carbon Trust, 2013)



For floating structures, j-tube and j-tubeless systems are not possible, so cables hang freely from the structure to the seabed, where they can then be buried. While this reduces the potential for damage from pulling the cables through a j-tube, it brings additional challenges with regard to cable tangling and the cable dynamics. Free-hanging cables need to be able to withstand strong ocean currents, and the offshore wind industry has limited experience of this to date. Simulations and testing of dynamic cables was undertaken for the Fukushima Forward project, but only full-scale testing will truly assess performance, particularly over time when cables experience fatigue.

Availability of cable installation vessels is a potentially significant bottleneck in the offshore wind supply chain (see "Installation Vessels" for more).

Installation Vessels

Prior to 2013, offshore wind turbines in Japan were installed so close to shore that foundations and turbines could be installed from cranes located onshore (Figure 77). However, as projects move further from shore, vessel availability and capability will become increasingly important, and costly; for example, Vattenfall estimate vessel hire at £150,000 per day (Wind Energy Update, 2011).

Figure 77. Installation of monopile using onshore crane at Kamisu nearshore wind farm (Moricho, 2010)

Japan currently lacks an established offshore wind supply chain, and is currently reliant on a limited number of vessels from other industries (Table 13). There are very few vessels available which have sufficient lifting capacity to install gravity foundations, which caused problems with the installation of the gravity base at Choshi demonstration project, and only one cable installation vessel. While current vessel availability should be able to cope with near-term demand, as deployment ramps up beyond 2020 this could become a major bottleneck. Given the long lead time for producing large vessels, Japan should get ahead of this problem now to avoid delays further down the line.

Table 13. Vessels available for offshore wind farm construction in Japan (4coffshore, 2013)

	Type	Owner	Name	Lifting capacity (t)	Project experience
	Floating sheerleg crane	Fukada Salvage & Marine Works	Musashi	3700	Kitakyushu (foundation)
	Floating sheerleg crane	Fukada Salvage & Marine Works	Suruga	2200	Kitakyushu (met mast)

	Revolving heavy lift barge (floating)	Yorigami Maritime Construction	Shinsho	1600	Choshi (foundation)
	SEP/Heavy lift barge	Daiichi Kensetsu Kiko	Kuroshio	3600	Kamisu; Choshi; Kitakyushu (turbine)
	SEP/Jack-up barge	Daiichi Kensetsu Kiko	Aso	1600	Setana (turbine); Choshi (transported turbine components)
	SEP/Jack-up barge	Daiichi Kensetsu Kiko	Mutsu	1600	None
	Cable lay barge	Enkai Kaihatsu Kougyou	Kaisei	50	Choshi; Kitakyushu (export cable)

Installation efficiency can also be improved through developing bespoke offshore wind vessels. Existing vessels have limited carrying capacity for turbine components and foundations. However, in Europe, vessels are being designed to carry up to 8-10 turbines at a time, which allows more turbines to be installed over shorter time periods. This is particularly significant given the limited number of days available for installation.

Japan already appears well placed to tap in to this market. Marubeni and Innovation Network Corporation of Japan recently purchased SeaJacks, a British firm that designs and builds bespoke installation vessels for the offshore wind industry. The acquisition was funded by a loan from six of Japan's largest banks, totalling 20 billion yen (US$252 million). Japan also has significant capability in manufacturing large vessels, and growth in the offshore wind industry would provide a boost to Japanese shipbuilding companies.

For floating projects, since the majority of construction is performed onshore, only relatively small tug boats are needed for installation. These appear to be readily available in Japan, and can be produced quickly with limited bespoke design specifications when demand increases.

Figure 78. Floating substation for Fukushima demonstration project being towed out to site using simple tug boats (Renewables International, 2013)

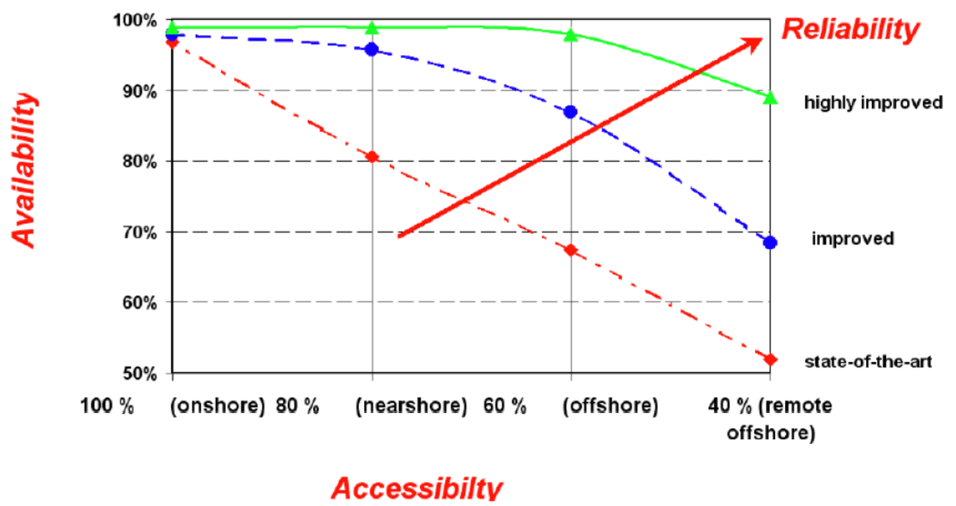
6.4 Operations & Maintenance

Operations & Maintenance (O&M) typically accounts for ~25% of total project costs (GL Garrad Hassan, 2013d), and involves ensuring that the project runs safely and cost-effectively, maximising energy output to provide commercial returns to the developer. This predominantly involves inspecting, maintaining, and repairing the wind turbines. This activity is usually initially conducted by OEMs during a specified warranty period for the turbines, which is negotiated with the developer, but typically ranges from 2-5 years. Once the warranty expires, responsibility for turbine maintenance passes on to the developer, or a third party contractor.

Japan has little experience of undertaking repairs offshore. While Japanese OEMs can leverage experience from conducting maintenance on turbines in the onshore industry, offshore wind farms present far more complex and challenging issues. There is therefore a need to up-skill staff to be able to conduct repairs offshore, as well as developing more knowledge and capability to improve the performance of larger offshore turbines.

The reduced level of accessibility offshore increases the necessity for highly reliable turbines (Figure 79); thus the most effective way to reduce O&M costs is to improve turbine reliability. Most Japanese WTGs have been adapted from onshore models, and are new to the more complex and harsh offshore environments. Namely, they are at greater risk of damage from corrosion, over-heating, and freezing.

Figure 79. Impact of availability and accessibility on turbine reliability (Longyuan, 2013)



Scheduled vs. Unscheduled Maintenance

Maintenance to turbines is usually classified as either scheduled/preventative or unscheduled/corrective. While scheduled repairs are proactive attempts to extend the life of components or replace known parts which are suffering wear, unscheduled maintenance involves reactive repair and replacement of component failures. The aim is therefore to limit the amount of unscheduled maintenance as much as possible, to reduce down-time for the turbine.

The most effective way of doing this is by integrating a condition monitoring system within the nacelle to identify when components need maintenance before they fail. More pre-emptive activity allows maintenance of turbines to be planned for calm weather conditions and performed in bulk, which both keeps the turbine operating and minimises the number of costly trips to conduct unscheduled repairs offshore. For example, failures during winter months, when access is difficult, can lead to significant losses if a turbine is left idle and unable to produce electricity. Using condition monitoring systems to identify component repair in advance of failure also allows time to buy replacement parts. Japanese OEMs have already developed sophisticated condition monitoring systems from their onshore turbines, which can be adapted for offshore application. Condition monitoring systems have already been incorporated in Hitachi and Mitsubishi offshore turbines.

Design for Maintenance

Another means of minimising disruption to power generation and reduce the cost of O&M is to design the turbines for maintenance, using more modular designs. This allows small individual components to be repaired, rather than having to remove large features of the turbines. As well as limiting disruption, this also negates the need for large vessels and cranes to undertake repairs. The Mitsubishi SeaAngel has incorporated this concept of a modular design. The digital displacement transmission (DDT) consists of several hydraulic components which can be individually replaced in the event of a failure. Indeed, the turbine can still operate with failures to some components, with power outage being reduced rather than going idle (NEDO, 2013).

O&M Strategy

The O&M strategy employed is largely dependent on the location of the wind farm. Workboats will be used in all projects, but those further from shore will also use helicopters to improve access and sites many miles from shore may have an offshore base from which to conduct repairs. In the case of Japan, there will be a distinction in O&M strategies between fixed-bottom turbines, which are close to shore, and floating projects, which are located further offshore. For nearshore wind farms, located within 10km from shore, small vessels should be sufficient, since transit times by boat should be fairly short. However, for floating projects further from shore, more bespoke vessels may be required and helicopter access may sometimes be necessary. However, given that even floating projects are likely to be located within 25km from shore, the immediate focus should be on supplying enough suitable vessels to access the wind farms.

An alternative O&M approach for floating turbines is to tow the entire structure back in to port for dockside repairs, rather than having to do so offshore. However, this will only be applicable in the event of a major failure, rather than regular maintenance.

Access Vessels and Transfer Systems

The proximity to shore of Japan's existing offshore wind projects has meant that they could be accessed directly from land, using a simple gangway (Figure 80). However, safely and regularly accessing turbines offshore brings many new challenges. Indeed, this was flagged as a major issue in the demonstration projects at Choshi and Kitakyushu, with increased wave height offshore and lack of specialised transfer systems making it difficult to safely transport workers between vessels and the turbine during installation (NEDO, 2013). Particularly as projects move further from shore into harsher marine environments there will be an increasing need for bespoke vessels which can operate in difficult conditions and specialised transfer systems to transport workmen from the vessel to the turbines. Improving accessibility will result in less downtime and better project economics.

Figure 80. Gangway access from land to nearshore turbine at Kamisu nearshore wind farm (Moricho, 2010)

7 Synthesis

The energy landscape in Japan has changed dramatically since the Fukushima nuclear disaster in 2011. A country which prided itself on the energy security provided by its extensive nuclear fleet was forced to shut down all 50 nuclear reactors, representing 30% of its base load power (44.6 GW). Filling the void has proved extremely costly, with fossil fuel imports increasing national power generation costs by more than 40%. Japan is now the world's largest importer of liquefied natural gas (LNG), spending $100m per day on LNG. In 2012, this accumulated to 6 trillion yen ($60bn), compared to 3.5 trillion yen prior to the disaster in 2010. Petroleum imports have also risen by 35% since 2011.

Realising that this is unsustainable, the Japanese government are currently drafting a new national energy plan, which will set a new roadmap towards energy security and lower power generation costs. Given the level of investment the country has made in nuclear energy and the spiralling costs of importing alternative fuels, it is likely that more nuclear reactors will come back online over the coming year, provided they can demonstrate their resistance to earthquakes. However, there are also likely to be benefits for the renewables industry, through more ambitious national targets and a new feed-in tariff (FIT) for offshore wind.

The FITs announced in the aftermath of the Fukushima disaster were some of the most competitive in the world, triggering enormous growth in the solar industry and moderate growth in onshore wind (growth has been held back by long environmental impact assessments, with more capacity expected to come online in the next couple of years). However, the potential for onshore wind in Japan is limited by geographical constraints, with offshore wind holding greatest potential to expand Japan's wind power capacity. Japan has an estimated 1,570 GW of offshore wind potential, in comparison to 280 GW onshore. However, 80% of this resource (1,170 GW) is located in water depth >100m, which can only be harnessed using floating turbines.

With over 20 years of government-funded research, Japan has become the world leader in floating technology. The recently installed full-scale projects at Fukushima and Kabashima confirm this status, with significant investment flowing into both projects. Fukushima, in particular, is the flagship testing bed for floating wind in Japan, and the world. METI has already invested 22 billion yen in the first phase, and plans to invest a further 31 billion yen in the second phase of the project, with plans to potential expand the site to 1 GW installed capacity.

However, the cost of floating wind power is significantly higher than for fixed foundations, with floating structures typically costing 4-6 times more than fixed-bottom foundations (50 JPY/kWh vs 200-300 JPY/kWh). Over the short- to medium-term Japan is therefore likely to focus on developing fixed-bottom sites, with a view to building capability in developing projects offshore until floating structures become cost-competitive. Portside projects at Kamisu, Sakata, and Setana have proved successful and there are plans to expand Kamisu to 250MW. However, Japan has very little experience of developing truly offshore projects and faces a steep learning curve in addition to some unique challenges caused by their geotechnical and meteorological conditions.

NEDO has funded two successful demonstrations in offshore locations, at Choshi and Kitakyushu respectively, which have proved extremely valuable in identifying the technical challenges facing the industry. Availability of installation and access vessels appears to be a major bottleneck, and developing the necessary infrastructure and a strong supply chain will be key. A major challenge in Japan is the unique threat from strong ocean currents and extreme events, such as typhoons, earthquakes, and tsunamis. Simply adopting European methods may therefore not always be applicable, and bespoke local solutions may be required.

For example, while monopiles are currently the most economical solution for most European projects, they are potentially vulnerable to damage from seismic activity, which may encourage greater uptake of gravity base foundations. Furthermore, jacket foundations may be more resistant to strong ocean currents and tsunamis. There may also be more novel, alternative structures which are applicable to Japanese coastal areas. Essentially the key driver will be cost, and an assessment of risk will need to be undertaken, informed by the data collected at demonstration projects such as Choshi and Kitakyushu. Developers are likely to see benefit in having different types of foundation solutions, along with monopiles, to provide technical options for securing backing from investors in future projects (Recharge, 2014).

Floating turbines also face considerable technical challenges, both to prove the technology and, importantly, reduce costs. Three foundations concepts dominate the designs being developed, but a clear winner is yet to emerge, with variations of semi-submersible platforms and spar buoys being trialled in Japanese waters. There is potential for floating wind to reduce costs and become competitive with fixed structure in water depth >50m; however, a number of challenges with regard to moorings, full structure modelling, dynamic sub-sea cables, wake effects, and O&M strategies need to be overcome.

Perhaps the biggest challenge to offshore wind development, and renewables in general, is the lack of grid transmission capacity. Japan's most abundant wind resource is located in areas far away from demand centres, making inter-regional transmission necessary. Yet the structure of Japan's electricity market, dominated by regional monopolies that have traditionally supplied their own energy locally, means that the grid system is not equipped to handle significant transmission across the country. Considerable grid reinforcement and transmission upgrades are therefore necessary if Japan is to increase its share of renewable energy.

In addition to the technical challenges, Japanese utilities are reluctant to increase their share of renewables, preferring to restart nuclear reactors, which they have invested heavily in and provide a steady source of electricity, in contrast to the variable output from renewables. Electricity market reform is expected to begin to liberalise the retail market and separate generation, transmission, and distribution assets by 2020, and there are calls to force power companies to buy electricity from renewables by law. However, it will remain to be seen how much influence the powerful utilities have on the changes.

Another major issue is consenting, particularly the conflict with local fisheries. Fishing coops are extremely powerful in Japan and can exert considerable influence over maritime development. Furthermore, common law dictates that fishermen have the right to manage coastal areas and must be compensated if their operation is obstructed. Early engagement is therefore crucial to earn the support of local communities and bring fishermen on-side, as proved to be the case in Kabashima, Choshi, and Kitakyushu. This is likely to remain a key issue for offshore wind developers and there is a need to work with unions to determine new fishing methods near turbines.

Tied to the issue above, extensive environmental impact assessments (EIA) are proving a major barrier to project consenting. In Japan, EIAs typically take 3-4 years and can be extremely costly, with Eurus Energy claiming EIA costs of up to 100 million yen (Recharge, 2014). Significant work needs to be undertaken to better understand the impact of turbines on bird populations and the impact of foundation structures and mooring chains on marine mammals. The MOE has commissioned a study around the floating demonstration at Kabashima, which will provide a model on which to base future offshore projects; however, there is considerable scope for more work in this area.

There are therefore significant challenges ahead for Japan's fledgling offshore wind industry. Building the necessary grid infrastructure to relieve transmission bottlenecks and streamlining consenting processes will prove major hurdles, and there are considerable technology challenges which need to be overcome, particularly coping with extreme events such as typhoons, earthquakes, and tsunamis. However, offshore wind also presents a major opportunity for Japan to strengthen its energy security, reduce carbon emissions, and create an industry which can boost the economy domestically, as well as provide an opportunity for exports. Japan has a strong maritime heritage, well-established steel production capabilities, and a track record in manufacturing and mass production. The key will be stimulating the necessary investment to reduce technology costs.

2014 is likely to be a crucial year for the prospects of Japan's offshore industry. The new national energy plan can give a huge boost to renewables, and a competitive offshore wind FIT can kick-start the country's enormous potential to become a future global leader in offshore wind technology. Up until recently, funding has mostly come from government, but private investment is expected to increase following the introduction of new feed-in tariff incentives. However there is pressure to justify the investment, and a need to commercialise the technology.

Japan has not had the experience and know-how of building and maintaining wind turbines in the ocean and cannot simply apply European methods as the climate and geology are very different. However, there are opportunities to share learnings and experience to develop the technologies and regulatory and market conditions to foster an industry with enormous potential. Exchange of information and knowledge with foreign manufacturers, developers, scientific institutes, and government organisations could unlock benefits for all parties.

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