COMMERCIALIZATION OF FLOATING OFFSHORE WIND POWER SPEEDS UP IN EUROPE

– EXPECTATIONS ARE ALSO HIGH IN JAPAN, WHICH ASPIRES TO DEPLOY UP TO 45 GW OF OFFSHORE WIND POWER BY 2040 –

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SUMMARY

- Floating offshore wind power has significant potential because the turbines can be installed over a wider area than is possible with the fixed foundation system. Adoption of the technology is expected to increase in the future, and there is ample room for its deployment in Japan.

- With several floating foundation technologies having progressed to the pre-commercialization stage through the demonstration projects conducted to date, the implementation of large-scale projects is accelerating, particularly in Europe, with the aim of addressing the challenges of reducing costs and acquiring operational know-how.

- Deployment of floating offshore wind power will expand in the future, mainly in Europe and Asia. By 2030, the total capacity in Europe, which is the leader in the field, is expected to reach 10 GW or more. For Japan, which aspires to strengthen its competitiveness in the offshore wind industry, cooperation with the Europeans will be needed to form a supply chain and acquire know-how.

INTRODUCTION

The offshore wind power generation, where the wind conditions are better than on land and it is easy to install large wind turbines, is expected to be a promising source of renewable energy. There are two types of offshore wind power: a fixed foundation system in which a foundation and a wind turbine are installed directly on the seabed; and a floating system in which a wind turbine is installed on a floating substructure anchored to the seabed. While most of the world's offshore wind farms currently use the fixed foundation system, suitable installation sites are limited due to such factors as the limitations on water depth. For this reason, expanding the deployment of offshore wind power requires the practical use of floating offshore wind turbines that can be installed in deep water and that offer the prospect of expanding the area over which they can be installed. In Japan, where the seabed terrain is marked by steep slopes, the potential for deploying floating offshore wind power[1], in terms of generated power, is estimated to be 424 GW[2], equivalent to about 200 nuclear power plants[3], greatly exceeding the 128 GW available from the fixed foundation system. However, the biggest challenge will be reducing the cost of construction, which is said to be double that of the fixed foundation system. While Japan, Europe, and the US lead the way in technological development, Europe, which accounts for 62 MW of the 74 MW of floating offshore wind power capacity currently connected to grids worldwide, leads the way in terms of

[1] Estimated by the Japan Wind Power Association. Provisional assumptions: Located within the Exclusive Economic Zone (EEZ), an annual average wind speed of 7.0 m/s or more, a water depth of 10-50m for fixed-foundation turbines and 100-300 m for floating turbines, and a minimum capacity of 120 MW per project.

[2] 1 GW＝1,000 MW＝1,000,000 kW

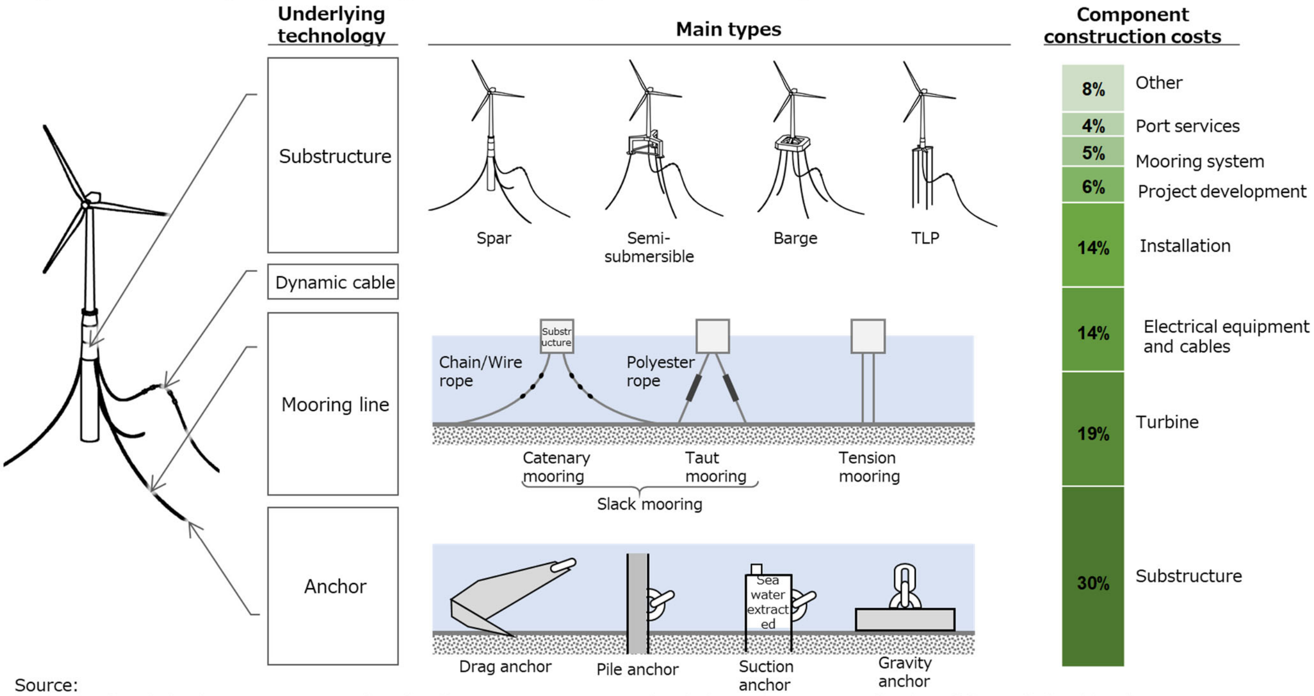
[3] The author's estimate. Assuming a floating offshore wind power capacity factor of 45%, a nuclear power plant output of 1 GW/plant and a capacity factor of 85%, (424 GW×45%) ÷ (1 GW/plant×85%) ≒ 224.5 nuclear power plants.

the scale of practical demonstration of the technology. Most recently, development of floating wind power technology has progressed almost to the point of commercialization, mainly in Europe, and the movement towards commercialization is expected to accelerate, including the announcement of large-scale demonstration projects. This report highlights the latest trends, the underlying technologies, and the future prospects of floating offshore wind power.

MAJOR UNDERLYING TECHNOLOGIES FOR FLOATING OFFSHORE WIND POWER

As floating offshore wind turbines are required to generate a stable supply of power under severe weather conditions, and the effects of ocean currents and tidal currents, it is necessary to establish the underlying technologies as shown in Figure 1, including substructures to support large wind turbines, dynamic cables that provide both durability and power transmission capability, and mooring systems.

Figure 1 Underlying technologies for floating offshore wind power



Source:
i. Floating foundation images: *Ocean Engineering* "Human exposure to motion during maintenance on floating offshore wind turbines" (https://www.sciencedirect.com/science/article/pii/S002980181831254X Accessed June 2021)
ii. Mooring line and anchor images: Created by MGSSI based on "Floating Offshore Wind Power Technology Guidebook" NEDO (https://www.nedo.go.jp/library/fuuryoku_guidebook.html Accessed June 2021)
iii. Component construction costs: Created by MGSSI based on "Floating offshore wind factsheet" ETIPWind (The European Technology & Innovation Platform on Wind Energy)

Substructures account for 30% of the construction cost, and are the most important of the underlying technologies. It is necessary to minimize vibrations caused by wind and waves while supporting a wind turbine weighing several hundred tons or more. It is also important to reduce costs in such areas as structural design, manufacturing method, and offshore transportation, installation, and maintenance. The current mainstream substructures are mainly classified as being of the spar type, semi-submersible type, barge type, or TLP (Tension Leg Platform) type, each with different characteristics, including the level of technology readiness, applicable water depth, sea area, mooring method, required submarine geological conditions, and construction method (Figure 2). As a result of the research and development and the demonstrations conducted to date, the level of technology readiness of the spar-type and semi-submersible type substructures has progressed to the point of pre-commercialization, and the barge-type substructures have also completed the demonstration stage.

A dynamic cable is a cable that floats in the sea and transmits power from a floating structure to a facility such as an electrical substation. Dynamic cables require long-term insulation properties, mechanical strength able to withstand damage caused by tidal currents and the movements of substructures, and an installation design that resists bending caused by ocean currents. Furthermore, while the development of a 220 kV high-voltage

Figure 2 Comparison of the characteristics of mainstream substructures

	SPAR	SEMI-SUBMERSIBLE	BARGE	TENSION LEG PLATFORM
Photograph/ Image	 Photograph supplied by Toda Corporation	 Photograph supplied by Vestas Wind Systems A/S (Denmark)	 Photograph supplied by BW Ideol (France)	 Image supplied by MODEC
Technology readiness (note)	High, 30 MW pilot project completed	High, 25 MW pilot project completed	Medium, 3 MW demo project completed	Low, tank testing, technology demo stage
Equilibrium/Stability	Low center of gravity, high equilibrium & stability	High stability, low shake	Easily shaken	Highest stability, almost no shake
Water depth/ sea area	100 m water depth required, suitable even for sea areas with severe wave conditions	Suitable for a wide sea area as can be installed from depths of 40 m	Can be installed from depths of 30 m, but requires calm sea area as easily shaken	Can be installed at depths of 50 m or more, but not suitable for soft seabed
Manufacture	Simple structure enables easy manufacture, cost reductions are expected	Complex structure, substantial welding work, complex manufacturing process	Mass is high, but structure is simple and cost reductions are expected	Easy to manufacture due to small overall size and small components
Installation	Because the turbine is installed offshore, a lifting crane is required	The turbine and substructure are pre-assembled at the port and can be installed by towing to the installation site	The turbine and substructure are pre-assembled at the port and can be installed by towing to the installation site	The turbine and substructure are pre-assembled at the port and can be installed by towing to the installation site
Mooring system	Slack mooring	Slack mooring	Slack mooring	Tension mooring
Maintenance	Difficult due to the deep draft	Can be returned to port for large-scale maintenance	Can be returned to port for large-scale maintenance	Easy to maintain due to simple structure and small size
Advantages	Cost reductions expected due to ease of manufacture	Suitable for wide sea area, easy assembling and installation	Easy to install without need for offshore construction	High stability, simple substructure. Occupies small seabed area.
Disadvantages	Difficult to install in relatively shallow waters less than 100 m deep	Structural mass required to maintain equilibrium, simplification of manufacturing is an issue	Significant shake, installation sites are limited	Mooring system is expensive and difficult to construct. Installation site limited by seabed conditions.
Representative operators	Toda Corporation, Equinor (Norway)	Japan Marine United, Naval Energies (France), Principle Power (US)	BW Ideol (France), Hitachi Zosen (Japan)	MODEC (Japan), Glosten (US)

Note: According to the Carbon Trust (an environmental consultancy originally established by the UK government and now independent), there are the following nine levels of technology readiness: 1. Initial Concept, 2. Proof of Concept, 3. Numerical Modeling, 4. Tank Testing, 5. Scaled Testing (<1 MW), 6.1-5 MW Demo, 7. >5 MW Demo, 8. Pilot (10-50 MW), 9. Pre-Commercial (50-200 MW). Beyond that is the commercialization stage.

Source: Created by MGSSI based on Carbon Trust "Floating Wind Joint Industry Project Phase Ⅱ summary report", NEDO "Floating Wind Power Technology Guidebook", Ministry of Land, Infrastructure, Transport and Tourism "Technical Standards for Floating Offshore Wind Power (revised March 3, 2020)", and material published by each company.

dynamic cable with less transmission loss is expected to enable the future development of large-scale floating offshore wind farms, there are various problems to overcome, including the fact that, compared to the current 66 kV cables, a 220 kV cable would have less torsional resistance because it will be heavier and harder with a larger bending radius.

Mooring systems consist of mooring lines and anchors. There are two methods of connecting a floating structure to an anchor fixed to the seabed depending on the degree of tension: slack mooring and tension mooring. Slack mooring includes catenary mooring, in which stability is maintained by the weight of the chain itself, and taut mooring, in which the mooring force is obtained by the elongation of the mooring line maintained in a state of tension through adjustment of initial tension. While catenary mooring allows for easy installation of anchors, the mooring lines extend across a large area and may interfere with shipping and fishing operations. Taut mooring using polyester rope enables a reduction in weight, but it requires the installation of an anchor with high holding power[4]. In tension mooring, a floating structure is pulled down into the water by a line under strong tension to generate buoyancy, and the challenge in this case is the development of high-strength materials such as high-tensile cable. At present, suction anchors, which are fixed in place using pressure differentials, and drag-embedded anchors are the most commonly used anchors because of the ease with which they can be installed and removed. Research in areas such as development of low-cost materials, anchor sharing, and optimized design of mooring systems is also underway with a view to further reducing the cost of mooring systems.

[4] Holding power: The holding force of the anchor that is the basis of the mooring force when holding a floating offshore drilling unit in the anchor position. (Source: Japan Oil, Gas and Metals National Corporation)

Future implementation and commercialization require the optimum combination of substructure and mooring systems to suit the conditions at the installation site such as the water depth, sea state, and the condition of the seabed. In addition to the readiness level and the cost, it is essential to systematically evaluate each of the underlying technologies based on the supply chain situation, such as the manufacture and construction of large offshore structures in the area concerned.

Several other elements will be required in addition to the above to realize large-scale commercialization in the future, including the integrated design of wind turbines and the substructures on which they are mounted, the mass production of substructures, low-cost construction, floating offshore substations, attitude control, and maintenance-free technology.

LARGE-SCALE DEMONSTRATION PROJECTS INCREASING MAINLY IN EUROPE

In March 2021, the European association WindEurope declared that substructure technologies such as semi-submersible systems and spar systems are being established through the demonstrations conducted to date, and argued that it is necessary to scale up their deployment in order to realize the further reduction in costs and development of mass production systems that are required to achieve future commercialization. Seven European countries are already planning to deploy floating offshore wind power in the next decade. With Europe expected to deploy cumulative 300 MW or more of floating wind power by 2022, it will continue to lead the world in scale. Figure 3 shows the projects currently planned in various countries.

Figure 3 Floating wind power projects scheduled for operation in various countries

First power	Country	Project	Developer	Capacity (MW)	Turbine rating (MW)	Purchase price (€/MWh)	Substructure	Substructure supplier
2021/2022	France	Eoliennes flottantes du golfe du Lion	Engie, EDP, Caisse des Depots	30	10	240	Semi-sub	Principle Power (PPI)
2021/2022	France	EolMed (Gruissan) Pilot Farm	Qair, Total	30	10	240	Barge	BW Ideol
2021/2022	France	Provence Grand Large	EDF Energy	25.2	8.4	240	TLP	SBM Offshore
2022/2023	France	Eoliennes flottantes de Groix et Belle-Ile	Shell/EOLFI, China General Nuclear Power Group (CGN)	28.5	9.5	240	Semi-sub	Naval Energies
2021/2022	Norway	Hywind Tampen	Equinor	88	8	Off-grid	Spar	Equinor
2022	Ireland	AFLOWT	EMEC, SEAI, Saipem	6	6	Unknown	Hexafloat	Saipem
2023	US (Maine)	Aqua Ventus I	University of Maine	11	11	190	Semi-sub	University of Maine
2021/2022 (note)	Japan	Goto Offshore Wind Power Project (provisional)	Toda Corporation	22	2～5	Unknown	Spar	Toda Corporation
2021	China (Guangdong)	Jie Yang	Three Gorges Corporation	5.5	5.5	Unknown	Semi-sub	Mingyang Smart Energy
2026	South Korea (Ulsan)	Donghae-1	Korea National Oil Corporation (KNOC), Equinor	200	Unknown	Unknown	Spar?	

Note: According to the funding status report for the green bond issued by Toda Corporation to fund construction of the project, no wind power generators had been built as of March 31, 2020.

Source: Created by MGSSI based on Carbon Trust "Floating Wind Joint Industry Project Phase Ⅱ summary report", 4C Offshore's website, and material published by each company

The Scandinavian energy giant Equinor has used its know-how in offshore oil development to create the Hywind spar-type substructure. Since 2017, the Hywind Scotland demonstration project with a capacity of 30 MW has been conducted off the coast of Scotland, and it achieved an average capacity factor in excess of 54% during two years of operation. Equinor is also building a larger 88 MW floating offshore wind power project, the Hywind Tampen, in the North Sea, which is expected to power offshore oil platforms by 2022. Through this project, Equinor aims to reduce the LCOE[5] to 150 euros/MWh[6] or less, and plans to proceed to full-scale commercialization producing in excess of 200 MW by around 2025.

In May 2021, France announced a tender for a floating offshore wind power project with a capacity of 230-270 MW off the coast of Brittany in northwest France, and the French substructure manufacturer BW Ideol has

[5] Levelized Cost of Electricity: The unit cost of electricity obtained by dividing the cost required for generation, including capital, operation, maintenance, and fuel costs, by the amount of electricity generated over a plant's lifetime.

[6] 1 MWh＝1,000 kWh

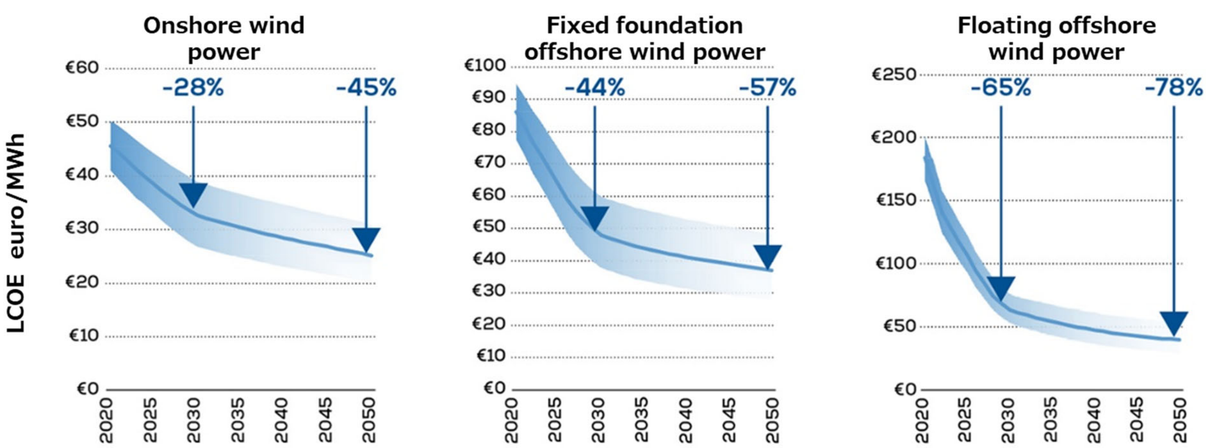
announced that it will enter a joint bid with an unnamed public utility company. The maximum tender price for this project has been set at €120/MWh, which is half of the €240/MWh of the demonstration project conducted in the adjacent sea area in 2015. France also plans to put a further 500 MW out to tender in 2024, and is moving towards full-scale commercialization.

In 2021, progress was made in Asia, not just in Europe. In May 2021, the Three Gorges Corporation, a leading Chinese state-owned renewable energy company, manufactured, on a trial, a 5.5 MW demonstration wind turbine using a semi-submersible substructure, and the company has announced that it plans to conduct China's first floating offshore wind power demonstration operation at its offshore wind farm off the coast of Guangdong Province. China General Nuclear Power Group (CGN), which invested in a project currently under development by France's EOLFI[7] for the purpose of acquiring know-how, is also planning to undertake a large-scale project off the Guangdong coast. Over the last few years, China has built up the world's second largest fixed-foundation offshore wind power capacity, and it has the potential to make great strides in floating systems going forward. In May 2021, South Korea, which aspires to become one of the world's top five offshore wind energy powerhouses, announced a plan to build a 6 GW (in total) floating offshore wind farm off the coast of Ulsan by 2030 through a public-private partnership. In addition, the feasibility study for a 200 MW project under development off the coast of Ulsan since 2019 by Korea National Oil Corporation and Equinor was completed in May 2021, and construction is scheduled to commence in 2022 with a view to starting operation in 2026. In Japan, where the deployment of offshore wind power is being accelerated in accordance with the Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities, which came into effect in 2018, the result of a public tender to develop a 16.8 MW (in total) floating offshore wind power project off the coast of Goto in Nagasaki Prefecture was announced in June 2021, with the selection of a consortium of operators led by Toda Corporation.

FUTURE OUTLOOK

The LCOE of floating offshore wind power is expected to decrease significantly after 2025 due to the acceleration of technological development and the implementation of large-scale projects. According to a report by ETIPWind, the LCOE, which in 2020 stood at €165-202/MWh, is expected to fall to €53-76/MWh (approximately ¥7.1-10.28/kWh) by 2030, well below the demonstration research target of ¥20/kWh by 2030 to which NEDO aspires. Furthermore, by 2050, the average LCOE for floating offshore wind power is expected to drop to €40/MWh, approaching the €37/MWh average expected for fixed-foundation installations (Figure 4).

Figure 4 European wind power LCOE forecast

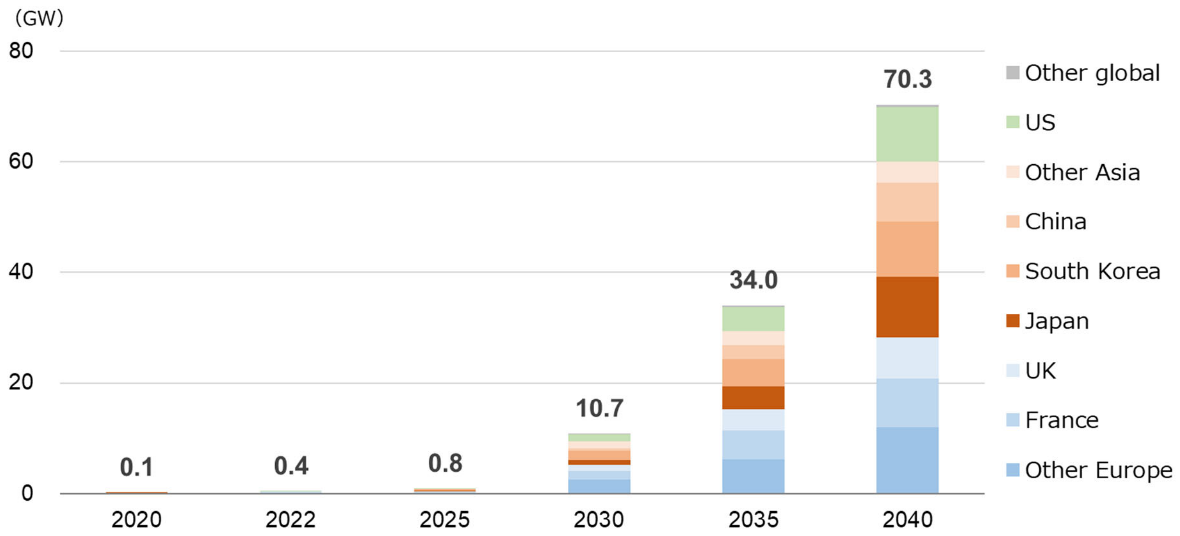


Source: ETIPWind "Getting fit for 55 and set for 2050" (https://etipwind.eu/publications/getting-fit-for-55/ Accessed June 2021)

[7] EOLFI was acquired by Shell at the end of 2019.
[8] Exchange rate: €1 = ¥134

As the cost falls, the deployment of floating offshore wind power will grow, particularly in Europe, Asia, and the US. The Carbon Trust forecasts that total global deployment of the technology will reach 10.7 GW by 2030 and 70.3 GW by 2040 (an estimated annual generated power of approximately 277TWh[9]) (Figure 5). From 2035, due to the potential to deploy floating offshore wind power coupled with the need to achieve decarbonization, the total capacity of floating wind power deployed in Asia is expected to increase significantly, particularly in Japan, South Korea, and China, and to overtake that of the European market. In Japan, which aims to deploy 30-45 GW of offshore wind power (including floating offshore wind power) by 2040, it is expected that about 11 GW of that power will be provided by floating wind power installations.

Figure 5 Global floating offshore wind power deployment forecast



Note: Figures from 2022 are expected values, figures from 2025 are estimates. "Other Europe" includes Portugal, Spain, Norway, Greece, and Turkey.
Source: Created by MGSSI based on Carbon Trust "Floating Wind Joint Industry Project Phase Ⅱ summary report"

Europe aims to form supply chains while proceeding with large-scale demonstration projects. With the mass production of components promoted and offshore know-how in construction and maintenance accumulated, Europe is likely to become the leader in the floating offshore wind power industry and can be expected to enter the promising Asian market. Indeed, many of the most recent developments in Japan, South Korea, and China have been promoted through collaboration with European companies. Japan aims to strengthen its competitiveness in the offshore wind power industry, including floating wind power, and plans to enter the Asian market. As Japan needs to work with the European leaders in the field of developing essential underlying technology, mass producing components, reducing the cost of construction technology, and acquiring management experience, most attention should be paid to the current developments in Europe.

[9] The author's estimate. The expected annual capacity in the case of 70 GW of wind power in 2040 calculated using an average capacity factor of 45%: 365 days × 24 hours × 45% × 70.3 GW ≒ 277 TWh. 1 TWh = 1 billion kWh.