ACCELERATING SOUTH KOREAN OFFSHORE WIND THROUGH PARTNERSHIPS

A SCENARIO-BASED STUDY OF SUPPLY CHAIN, LEVELIZED COST OF ENERGY AND EMPLOYMENT EFFECTS

MAY 2021

AEGIR | PONDERA | COWI

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FOREWORD Embassy of Denmark

Denmark and Korea have worked closely together in the Green Growth Alliance since 2011. Through the alliance, our governments and companies have fostered strong partnerships, innovation and joint investments. We have shared our experiences with Korea and learned from Korea. And we will continue to do so.

Our cooperation has intensified not least after the Korean government introduced its ambitious 3020 plan of 20 % renewable energy by 2030. This is a good example of government-led action - ensuring broad implementation and monitoring progress.

In connection with the 2021 P4G Seoul summit, it is a pleasure to introduce this timely and needed study of the cost of energy for future offshore wind farms in Korea and how we can lower the costs, increase competitiveness and join forces together.

I would like to take this opportunity to thank the consultants COWI, Aegir and Pondera for their tireless efforts to realize and complete this study on time. Also, a special thank you to Korea Energy Agency, Korea Energy Economics Institute and Green Energy Strategy Institute for their support on this study.

I want to thank the Netherlands for taking the opportunity to join and support the study via our existing MOU on Renewable Energy between Netherlands and Denmark.

It goes without saying that the final thank you note goes to Danish Energy Agency for their interest and financial funding of the study.

I hope our study can contribute to bringing forward new ideas, partnerships and initiatives that will secure the strong effective implementation of the Korean RE3020 plan. For the mutual benefit of Korea, its people and economy.

I wish you a joyful reading!

Seoul, May 2021

Jacob Rasmussen

Embassy of Denmark in Korea,
Energy & Environment Counsellor

FOREWORD Embassy of the Netherlands

The Netherlands and Korea are longstanding partners in many fields, ranging from business to culture and sports. This year 2021 is of particular significance as we celebrate 60 years of diplomatic ties. We look forward to continuing this close cooperation in the next 60 years. Offshore wind energy is one such opportunity for future cooperation. It fits perfectly in our countries' shared ambition for a sustainable future. Over the past years, the Netherlands pioneered in offshore wind and developed an efficient approach for the realization of offshore wind farms.

It is a great development that Korea has taken up an ambitious target for offshore wind, aiming for 12 GW in 2030. We are keen to share our lessons learned and contribute to the success of this ambition. This report kicks off that exchange.

This report was made in close cooperation with a number of partners:

We first of all would like to thank the Danish embassy for initiating this report and for the pleasant cooperation. We also thank the Danish Energy Agency. The Danish colleagues contributed greatly with their extensive network and knowledge of offshore wind in Korea. This cooperation was the first under the MoU on cooperation in the energy transition between Denmark and the Netherlands that was signed in 2020.

Second, we would like to thank the consultants Pondera, COWI and Aegir for a job well done. Their high quality standards made most of the report.

Last but not least we thank the Dutch ministry of Foreign Affairs and the Netherlands Enterprise Agency for their interest and financial support.

This report reviews the offshore wind developments in Korea and explores options for partnerships between the Korean, Dutch and Danish offshore wind sectors. We are excited about the result and hope it will be the start of a flourishing international cooperation.

Seoul, May 2021

Embassy of the Netherlands in Korea

EXECUTIVE SUMMARY

With its plans to reach 12 GW installed offshore wind capacity by 2030, Korea is making a commitment to a lower-carbon future and to growing its offshore wind industry from today's early stages into a global powerhouse. The goal of this study is to support Korean policymakers in making this plan a reality, by examining the status quo, quantifying expected developments, identifying key challenges to implementation and proposing solutions.

While Korea is in an excellent starting position compared to other emerging markets, this analysis shows that continuing with the status quo will endanger the 2030 goal for offshore wind. Partnerships are an effective way to mitigate this risk.

Policy environment

A policy environment which appropriately allocates risk and provides certainty to wind farm developers is essential to the success of the offshore wind industry in any country. In addition to driving build-out speed of offshore wind, the policy framework also directly impacts the cost of energy, as the costs of risks and inefficiencies faced by wind farm developers ultimately are reflected in the cost of energy. Despite the Korean government's ambition and efforts until now, the current level of wind farm developers' risk is considered high compared to the mature European development environment. The plans to alleviate these issues should be implemented rapidly.

Supply chain

In addition to the need to establish a favorable policy environment, accelerating offshore wind power in Korea hinges on the industry's ability to establish a sustainable and effective supply chain. This supply chain will determine not only the speed of adding offshore wind capacity, but also its cost. In terms of domestic supply chain capability, Korea's strong capabilities in steel, shipbuilding and cables put the country in an excellent starting position. If the capacity of the domestic supply chain is rapidly expanded, Korea has the potential for domestic companies to deliver a large share of the planned 12GW. The Tamra and Southwest Sea offshore wind farms were executed by domestic Korean suppliers, but these projects also revealed the need for significant improvement, especially in installation times and efficiency.

In the next years, the wind turbine supply is expected to remain the weakest link of the Korean supply chain:

- Domestic OEMs Doosan and Unison have announced significantly larger turbine models than their current models – 8 MW and 10 MW respectively – which are expected to lessen, but not fully close, the competitive gap to global OEMs like Vestas, Siemens Gamesa and GE
- Many developers and investors see the risk of using these new Korean turbines as prohibitively high
- Domestic production of turbines will also be a challenge; it would need to expand by a factor of 10 in order to deliver 12GW in the coming 8 years

Therefore, even with Korea's strong starting position, it will be extremely challenging to meet the 2030 target by relying solely on the domestic supply chain due to:

- Limited experience in project planning, financing and management
- Low competitiveness and limited track record of domestic turbines, leading to hesitancy of project developers to use them
- Low capacity for turbine manufacturing
- Lead times for transfer and buildup of XL monopile foundation manufacturing
- Installation vessel bottlenecks
- Slow pace of installation speed

Power of partnerships

To accelerate the expansion of offshore wind in Korea and increase the chance of meeting the 2030 target, it will be important to benefit from the global industry learning to date and leverage the knowledge and experience of mature industry leaders. This can be done through partnerships between Korean and foreign companies which can:

- Mitigate capacity risks, alleviating bottlenecks such as vessels and wind turbines
- Transfer knowledge to domestic partners
- Increase the speed of build-out by using state-of the art technology and optimized methods

In order to quantify the economic impact of this approach, a "partnership scenario" and a "domestic scenario" were developed within this study. The partnership scenario takes the most capable parts from both foreign and Korean supply chains while the domestic scenario relies solely on Korean supply.

Levelized cost of energy

By applying the scenarios to four reference sites o 500MW each, an analysis of the levelized cost of energy (LCOE) was performed for deployment in year 2026:

- LCOE for bottom-fixed sites is 75 EUR/MWh for the partnership scenario and 91-95 EUR/MWh for the domestic scenario, i.e. 22% more expensive
- This 22% LCOE difference equates to 870 million EUR (1.16 trillion KRW) in additional project costs for the 500 MW Incheon (fixed-bottom) reference site
- LCOE for floating sites is higher at 98-101 EUR/MWh for the partnership scenario and 116-120 EUR/MWh for the domestic scenario, due the higher cost of floating foundations, i.e. 19% more expensive
- The impact of using a domestic turbine is the primary driver for compared to the partnership scenarios
- New turbine platform developments always have the potential to be delayed or to underperform; if a developer had to fall back on a 5.5 MW instead of using an 8 MW turbine for a 500 MW project, an estimated 1.25 billion Euro would be lost, mostly due to lower energy

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Partnerships have the power to increase the speed and decrease the cost of offshore wind for Korea, while at the same time allowing domestic companies to leapfrog to best-in-class. The most efficient way of achieving Korea's goal of 12 GW by 2030 is by taking advantage of the lessons learned by European partners and embracing the support of the global industry.

Employment effects

The economic impact of a wind farm can be measured not only in cost but in the impact on domestic employment. Employment effects are measured in full time equivalent (FTE) years, which represent one year of work for one person. It is estimated that the reference sites will generate approximately:

- 16,079-27,452 lifetime FTE in the partnership scenario
- 24,626-33,566 FTE in the domestic scenario

Though the domestic scenario generates more FTE, the partnership scenario will likely compensate with a higher installation speed. Using the Incheon reference case as an example, the domestic scenario generates 24,626 FTE years for a 500 MW wind farm. If the partnership scenario can build 1000 MW in the same time, over 32,000 FTE will be generated. Floating wind farms generate more FTE than bottom-fixed due to their higher capital costs. In all scenarios, the peak job creation will happen during construction when many FTE are delivered during a short time frame.

Capturing economic value

This potential economic value can be best captured and retained long-term by a stable offshore wind pipeline, rather than a boom and bust cycle. If the pipeline is kept stable, the sector will remain in work and the growth, though it may be slower, will have a more long-term effect on the economy. Quick growth often has only a temporary effect which then afterwards leaves the sector unemployed for longer periods of time. A stable pipeline will also increase the likelihood of sustaining a local supply chain and thereby a high percentage of domestic supply.

When looking at the Korean offshore wind industry from a holistic perspective which considers cost of energy, speed of installation and job creation, a partnership approach offers the greatest value: lower cost of energy, organic growth, sustainable job creation and higher installation speed, while at the same time transferring knowledge and experience to Korean companies.

INTRODUCTION

1 Introduction

The aim of this study is to support the Korean government in the implementation of its *3020 Renewable Energy Implementation Plan* as it relates to the offshore wind sector. The RE3020 Plan sets a target to build 12GW of offshore wind by 2030. With Korean policymakers in mind, this analysis demonstrates the win-win impact of involving key foreign offshore wind industrial expertise to catalyze development of the Korean offshore wind market.

This impact is considered from a holistic perspective, beginning with an examination of the policy environment in Chapter 2. This chapter sets the stage for the rest of the report, by describing the environment in which offshore wind projects are developed in Korea and potential impacts to the timeline and cost of offshore wind energy expansion in Korea.

In addition to a favorable policy environment, the build-out of offshore wind energy in Korea will require an adequate supply chain to manufacture, install and operate the wind farms. This is examined in Chapter 3. This chapter identifies the current capabilities of the Korean supply chain and, using these as a basis, sets two supply chain scenarios which are referred to throughout the rest of the study.

In Chapter 4, the analysis becomes quantitative. Using key drivers of LCOE prices, indicative LCOE levels are mapped for both bottom-fixed and floating offshore wind farms with a heat mapping. Four wind promotion regions are selected as reference cases for a deep dive into LCOE, combined with the supply chain scenarios from Chapter 3. The chapter closes with a look at the trajectory of LCOE towards 2035.

Finally, the study concludes with analysis on the level of job creation expected from each reference case and scenario and with recommendations on how to retain the long-term economic value of such jobs creation.

The authors are grateful to the following companies for their support of this study:

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- Jeju Hanlim Offshore Wind Co., Ltd.
- Kim & Chang
- Korean Wind Energy Company Ltd.
- Korea Labor Institute
- Korea Wind Energy Industry Association
- Northland Power
- Ørsted
- Siemens Gamesa Renewable Energy
- Van Oord
- Vestas
- wpd

The following currency conversion rates are applied in this study:

- 1 Euro = 1,335 Korea won
- 1 Euro = 0.86 British pounds sterling
- 1 Euro = 7.43 Danish Kroner
- 1 Euro = 1.20 US dollars

POLICY ENVIRONMENT

2 Policy environment

How much it costs to produce a certain unit of energy is dependent on many factors, starting with the most fundamental: what is the policy framework of the market? The policy environment in which offshore wind energy is developed, constructed and operated is a major determinant of project risk and overall speed of the industry build-out. The costs of risks and inefficiencies are ultimately passed on to the consumer and so the policy environment has a major impact on cost of energy.

This chapter provides an overview of Korean policies with regard to renewable energy, focusing on offshore wind energy and compared with the corresponding European policies. In addition, it describes the current development stages and developers' incentives and risks. Derived from these factors, the current investment climate in the offshore wind industry in Korea is described.

2.1 Key renewable energy plans

Korea recently declared their target to become carbon neutral by 2050 and introduced several plans that address the buildout of renewable energy in general and offshore wind specifically. The following section describes the plans with the most relevance to offshore wind.

2.1.1 Renewable Energy 3020 Implementation Plan

In order to turn the conventional energy system into a low-carbon, renewable energy system and to create relevant jobs, the Korean government announced the Renewable Energy 3020 Implementation Plan (RE3020) in 2017, setting a goal to increase energy from renewable sources from 7.6% to 20% by 2030 and pledging to expand the offshore wind power capacity from the current 124.5 MW to 12 GW by 2030 [1]. The name of this plan "3020" reflects the government's goal by 2030 of generating 20% of power with renewables.

2.1.2 3rd Energy Masterplan and 9th Basic Plan

Korea's energy deployment and supply strategies are based on the Korea Energy Masterplan (established every five years for a planning period of 20 years) and the Basic Plan for Long-term Electricity Supply and Demand (established every two years for a planning period of 15 years). The 3rd Energy Master Plan in June 2019 focused on the innovative, green transition of the overall energy system – from production and distribution to consumption. The plan calls for:

- a significant reduction in coal-fired power generation
- no further lifespan extensions in aged nuclear power generation
- an increase in electricity generation by renewable sources

- and liquefied natural gas to confirm the government's goal to raise the share of renewable energy in power generation from 7.6% in 2017 to 30-35% by 2040 [2].

The 9th Basic Plan for Long-term Electricity Supply and Demand in 2020 announced targets for increasing the share of renewable energy to 40.9% of power capacity by 2034 from the current 15.7%. The renewable energy sources are targeted to increase to 77.8 GW and photovoltaic energy (45.6 GW) and wind power (24.9 GW) are expected to account for 91% of total renewable energy by 2034 [3]. Figure 2-1 displays the changes in national energy capacity mix targets by energy source in Korea according to the plan.

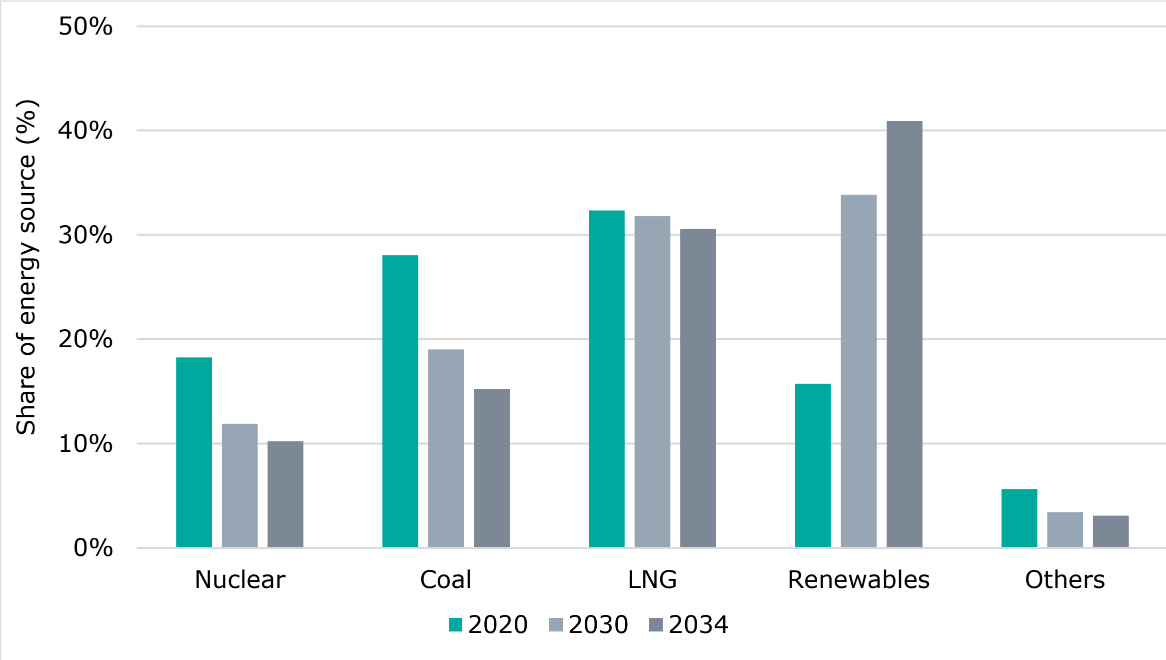


Figure 2-1 National energy capacity mix targets by energy source in Korea according to the 9th Basic Plan for Long-term Electricity Supply and Demand [3]

2.1.3 Green New Deal

In July 2020, President Moon announced that through the Green New Deal, renewable energy and eco-friendly business would be supported with KRW 73.4 trillion (EUR 55.0 billion) of governmental support and private investments to create 659,000 jobs and build a renewable energy infrastructure and more environmentally conscious firms by 2025 [4]. The administration has set out a direction for the country's energy industry "pursuing carbon neutrality" and "transforming the economic foundation to emit less carbon and be more eco-friendly". This masterplan is aligned with RE3020 and includes the following implementation plans for offshore wind promotion:

- Increase in government-led developments
- Establishment of a specialized organization to simplify permitting and licensing processes
- Candidate offshore wind zones to be announced in the first half of 2021

2.1.4 Fishing industry collaboration

The Ministry of Trade, Industry and Energy (MOTIE), the Ministry of Oceans and Fisheries (MOF) and the Ministry of Environment (MOE) jointly issued a "Plan for Offshore Wind Power Generation in Collaboration with Local Residents and the Fishing Industry" in July 2020 [5]. The goal of the plan is to install 12 GW of offshore wind power by 2030 to become one of the world's five largest offshore wind power generating countries, share the economic benefits of offshore wind development with local residents and the fishing industry and contribute the realization of the Green New Deal.

The plan includes government and local government-led siting, consideration zones and simplification of licensing procedures, increased residents' acceptance through the establishment of a support system suitable for offshore wind power, preparation and promotion of a win-win model for offshore wind power and fisheries and fostering the wind industry ecosystem in conjunction with large-scale projects.

2.2 Current state of Korean, Dutch and Danish offshore wind markets

In order to evaluate the impact of the national policy environment on development of the offshore wind industry, it is useful to look toward countries with mature offshore wind markets for comparison. Europe in general and Denmark and the Netherlands in particular can provide an excellent comparison. As global pioneers of offshore wind, Denmark and the Netherlands have a long history of continuously developing their policy frameworks to encourage the growth of offshore wind. At the same time, both countries have achieved remarkable decreases in the cost of offshore wind energy. The development of the offshore wind policy framework in the Netherlands and Denmark can best be characterized as a transition from leaving the project development to private developers, using the 'open door' principle, to a system in which the government has taken much more of the lead. The advantage of this approach is that the available space at sea can be used more efficiently (marine spatial planning) and that the interests of other stakeholders such as fishing, shipping and oil and gas extraction can be better considered. With this approach, it has also become possible for the governments to organize large scale competitive tenders in which each tenderer has an equal starting position, thereby promoting competition and with that, cost reduction.

In Section 2.2.1, a brief description is presented of the project development process in Denmark and the Netherlands and a comparison is made with the Korean process of project development.

Most public Korean offshore wind developers are state-owned power generation companies (GENCOs) which are subsidiaries of Korean Electric Power Corporation (KEPCO). GENCOs are obligated to generate more than a certain minimum percentage of gross power generation from renewable energy sources and are required to purchase more than a minimum amount of renewable energy certificates (REC) using the fixed price contract regime administered by the New and Renewable Energy Center.

Korean private developers are usually major construction companies and heavy industry companies. In addition to these big private developers, many small and medium-sized enterprises are also developing offshore wind farm projects as well.

As of March 2021, 42 offshore wind projects with a total development capacity of about 7.7 GW had acquired an Electric Business

License (EBL) [6]. The EBL is the first permit applied for after a successful wind measurement campaign and is therefore a good indicator of early project development. A list of these projects is given in Appendix A. According to the EBL list, 68.8% of the entire capacity is being developed by private parties and 17.9% is being jointly developed by public (government or GENCOs) and private parties. Only 13.3% or projects are being realized by solely public parties. Though some global offshore wind developers have recently announced their business expansion to the Korean offshore wind market, no foreign developers can be found on the EBL list. However, it should be noted that there may be foreign developers who are not visible because the structures of some SPCs are not specified on EBL list and not disclosed publicly.

In contrast to the 7.7GW of projects under development, just 140.1MW are in operation in Korea. These wind farms are mapped in Figure 2-2. The 140.1MW includes some test site, as well as commercial wind farms. These differences are specified in Table 2-1. Jeju Woljeong test site is not included in this table because it is currently not operational, and no plans are present to put this windfarm back in operation.

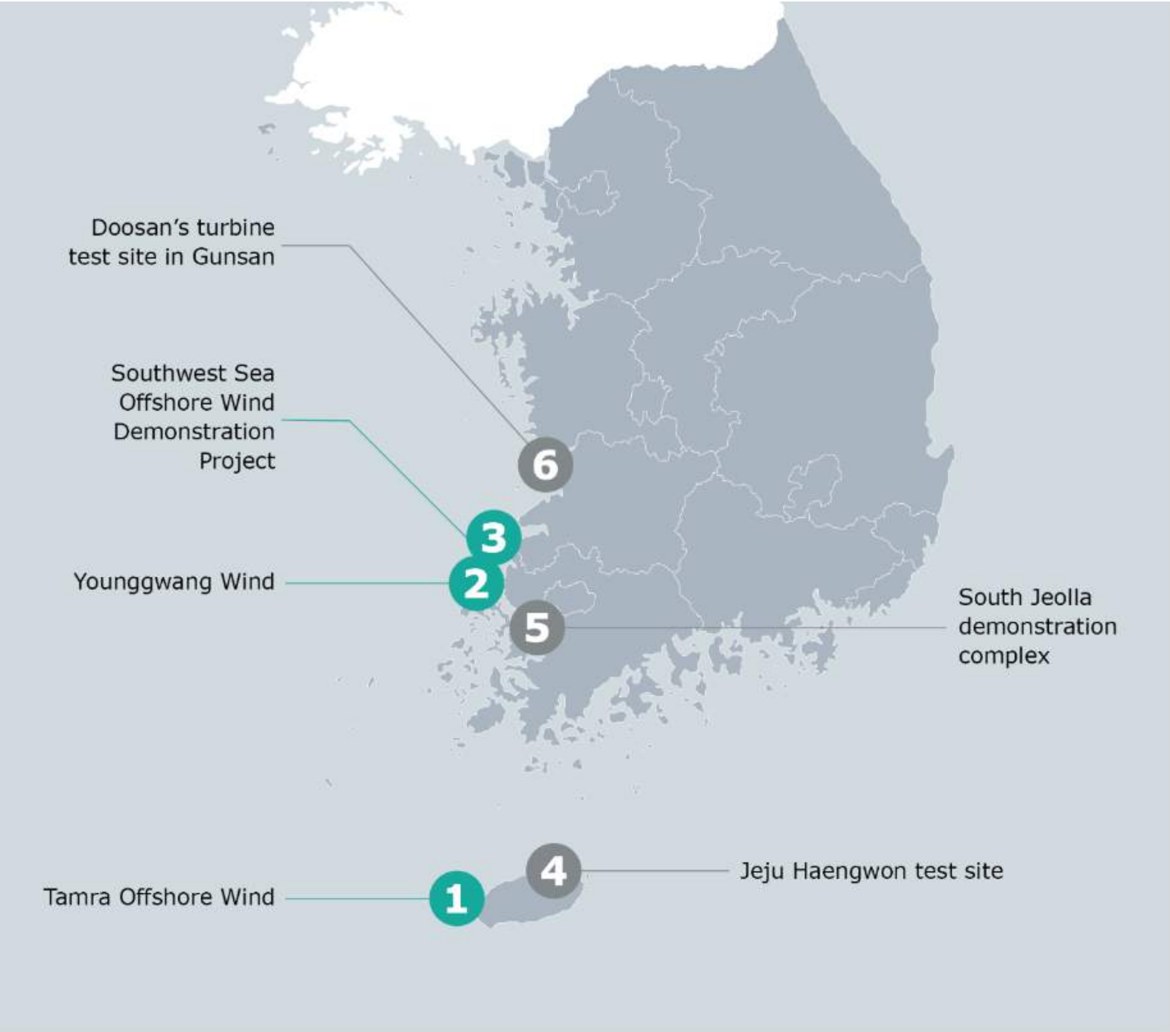


Figure 2-2 Map of offshore wind farms in Korea

Table 2-1 Operational offshore wind farms in Korea [7]

Wind farm	**Capacity**	**Turbine model**	**Turbine manufacturer**	**Year installed**
Tamra Offshore Wind	30 MW	10 x WinDS3000/91 (3MW)	Doosan	2016
Younggwang Wind	34.5 MW	15 x U113 (2.3 MW)*	Unison	2018
Southwest Sea Offshore Wind Demonstration Project	60 MW	20 x WinDS3000/134 (3MW)	Doosan	2020
Subtotal operating offshore wind	124.5 MW			
Jeju Haengwon test site	3 MW	1 x WinDS3000/91 (3MW)	Doosan	2014
South Jeolla demonstration complex	9.6 MW	1 x U113 (2.3MW) 1 x WinDS3000/91 (3MW) 1*U151 (4.3MW)	Unison Doosan Unison	2015 2016 2018
Doosan's turbine test site in Gunsan	3 MW	1 x WinDS3000/91 (3MW)	Doosan	2017
Subtotal offshore test turbines installed onshore	15.6 MW			
Total	**140.1 MW**			

** Onshore wind turbine models installed offshore*

Europe has the biggest offshore wind markets globally with a total installed capacity of 25 GW. Europe has over 15 years of experience and 5,402 turbines are currently connected to the grid. There are 116 operational offshore wind farms in 12 European countries. In the Netherlands, 537 turbines are operational, with an installed capacity of 2,611 MW and 559 turbines are operational in Denmark, with an installed capacity of 1,703 MW. Moreover, 8 offshore wind farms reached financial close last year, with construction expected to commence in 2021. There is a total of 62 MW floating wind in Europe by the end of 2020, which is 83% of the global floating wind capacity [8].

The EU Green Deal, the economic strategy for meeting both carbon neutrality and economic recovery, included an Offshore Renewable Energy Strategy for the deployment of 300 GW of offshore wind in the EU by 2050. The cumulative capacity of the installed offshore wind in Europe for the last 15 years is shown in Figure 2-3. The figure shows that Denmark was an early adopter of offshore wind and the decade between 2006 and 2015 saw 10-11GW in the whole of EU. An additional 14 GW was installed in the subsequent 5 years up to 2020 [8].

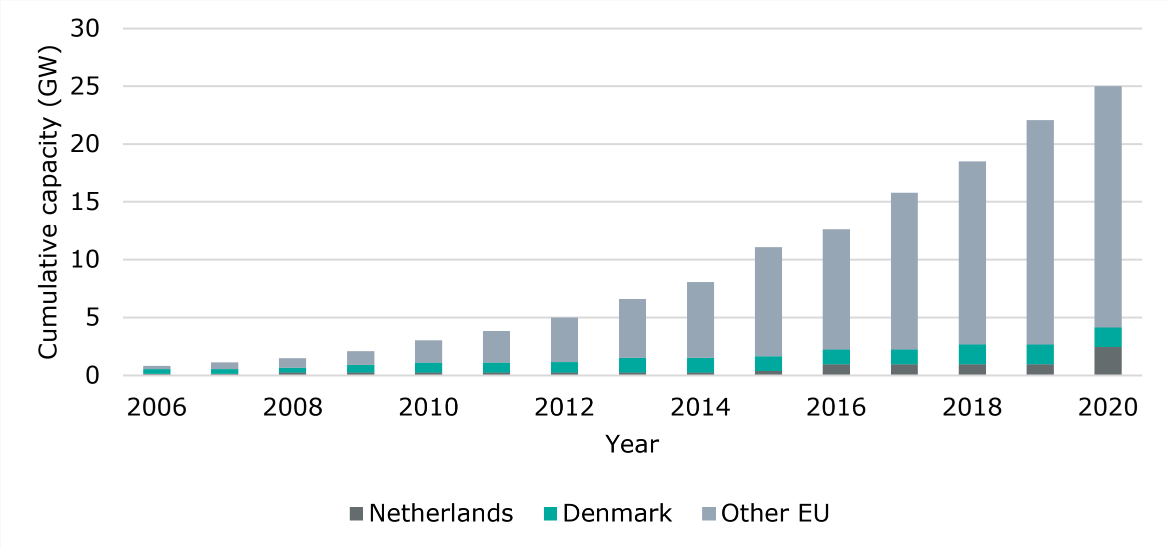


Figure 2-3 Cumulative capacity of the installed offshore wind in Europe for the last 15 years [8]

Table 2-2 presents the largest operating wind farms in the North and Baltic Seas, their installed capacity, and construction cost. This table only contains offshore wind farms with an installed capacity of 300 MW and more. The average cost of offshore wind farms in the North Sea and Baltic Sea is EUR 4-5 million per 1 MW of installed capacity.

Table 2-2 The largest operating wind farms in the North Sea and Baltic Sea [9]

Wind farm	Year commissioned	Installed capacity, MW	Total Capital Expenditures (billion EUR)	Capital Expenditures (mil. EUR/MW)	Country
Hornsea One	2019	1,218	3.4	2.8	UK
Borssele 1 and 2	2020	752	1.9	2.5	Netherlands
Borssele 3 and 4	2021	731.5	1.3	1.8	Netherlands
East Anglia ONE	2020	714	2.9	4.1	UK
Walney Extension	2018	659	2.0	3.0	UK
London Array	2013	630	2.4	3.8	UK
Gemini	2017	600	2.8	4.7	Netherlands
Beatrice	2019	588	2.9	4.9	UK
Gode Wind 1 and 2	2016	582	2.2	3.8	Germany
Gwynt y Môr	2015	576	2.7	4.7	UK
Race Bank	2018	573.3	3.0	3.4	UK
Greater Gabbard	2013	504	2.2	4.3	UK
Hohe See	2019	497	1.8	3.6	Germany
Borkum Riffgrund 2	2018	450	1.3	2.9	Germany
Horns Rev 3	2019	406.7	1.0	2.5	Denmark
Dudgeon	2017	402	1.7	4.3	UK
Veja Mate	2017	402	1.9	4.7	Germany
Rampion	2018	400.2	1.9	4.7	UK
BARD Offshore 1	2013	400	2.9	7.3	Germany
Global Tech I	2015	400	1.8	4.5	Germany

2.2.1 Project development process

The development of an offshore wind project is characterized by a large time lapse between the start of project development and the time that the wind farm starts to operate. In Europe, the development time is approximately 8 years, but there can be significant variations per project and countries. The procedure used in Korea for granting permits is the open-door procedure for offshore wind development, which is based on the principle that a project developer initiates the establishment of the project and takes all responsibilities for the development procedures necessary to complete the project.

The project developer is expected to conduct all project development activities and is responsible for all related tasks and investments, such as, site selection, site verification and application for all approvals and permissions. They are also responsible for managing complaints of local residents through prior discussion and consultation with the relevant government departments. Figure 2-4 shows the offshore wind farm development procedures in Korea.

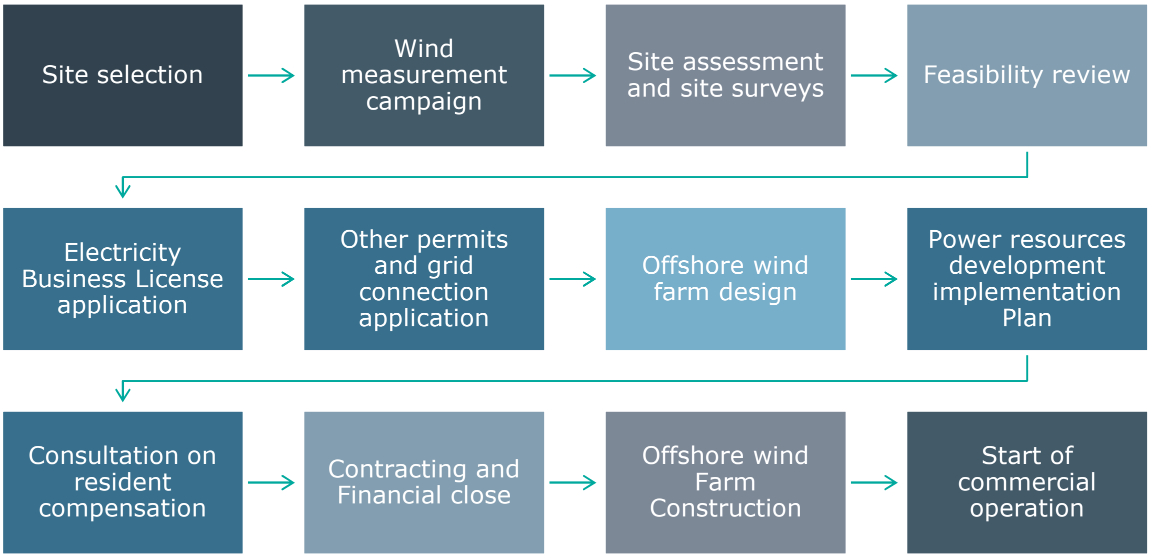


Figure 2-4 Offshore wind development procedures in Korea

The developer selects a potential offshore wind project site based on basic site data and the capacity of the planned power generation facility is determined concerning the Basic Plan for Long-term Electricity Supply and Demand. The feasibility of the project is determined through a site survey including costly offshore wind resource measurement campaigns using a Met mast or floating LiDAR, environmental impact assessment, grid connection review, and wind farm layout plan. After completing the wind measurement campaign, the developer applies for the EBL, which is the first permit necessary to continue with additional permit applications, the grid connection application and resolution of complaints of local residents.

Developers generally are granted a four-years period of exclusivity which starts when the permits to install the meteorological measurements equipment is granted. During this exclusivity period, MOTIE will not grant EBL to other developers for the permitted Effective Area, which is defined as an area of 100 km^2 per piece of measurement equipment permitted.

This process has led to a large number of EBL with a small average wind farm size of around 180 MW [6]. This contrasts with the European trend of wind farms steadily growing in size over the last years with an average size of 788 MW in 2020 [8].

Jeju Island differs from the central government policy and its development procedures. The local government of Jeju Island has created the Public Management System of Wind Resources clause through a revision of the Special Act on the Establishment of Jeju Special Self-Governing Province in 2011. Through the clause, the authority of the central government over offshore wind power generation projects was transferred to the governor of the Jeju Special Self-Governing Province [10]. In order to manage the site selection and permitting of offshore wind projects, the island launched Jeju Energy Corporation, a local government agency which is involved in selecting and developing offshore wind farm projects.

The procedures of Korean offshore wind development described differ from those of European countries. The "open-door" principle of developing offshore wind was used in the early years of development of offshore wind in Europe, however this resulted in a stagnation of offshore wind farm development as a result of a lack of regulation of site selection and permitting. The way of selecting areas for the future offshore wind farms in Europe is currently mainly divided into:

- "zone" siting, in which the government selects a wide area that allows the development of offshore wind farms, and
- "site-specific" siting, where development is allowed only in a smaller designated area selected by the government.

The Dutch and Danish governments are involved in all stages of development area selection, development licenses, construction permits, operating permits, grid connections and subsidies. The European experience has shown that complex permitting processes for offshore wind directly correlates with longer permitting times and increased risk for project developers. Increased risk for project developers leads to a high rate of unrealized projects and missing build-out targets. To simplify licensing and permitting procedures and reduce risk, the Dutch and Danish governments have introduced a 'one-stop shop' type of licensing process. Implemented by the Netherlands Enterprise Agency (RVO) and the Danish Energy Agency (DEA), these processes significantly reduce administrative procedures for developers and accelerate offshore wind energy development. These two government agencies are responsible for site selection, pre-site investigation, licensing, environmental impact assessment, grid connection and related infrastructure construction [11].

Compared to the unified permitting processed used in Denmark and the Netherlands, the disjointed permitting process in Korea is one of the main reasons that long lead times and risk of delays are anticipated. Other contributing factors are:

- lack of a mediation forum for resolving opposition of local residents
- uncertainties regarding grid connection
- lengthy permitting process

Projects have historically experienced extended periods of 8-11 years from first permit, EBL, to commercial operation date (COD). The development timeline (actual or projected, as applicable) from EBL to COD of four selected projects is shown in Figure 2-5.

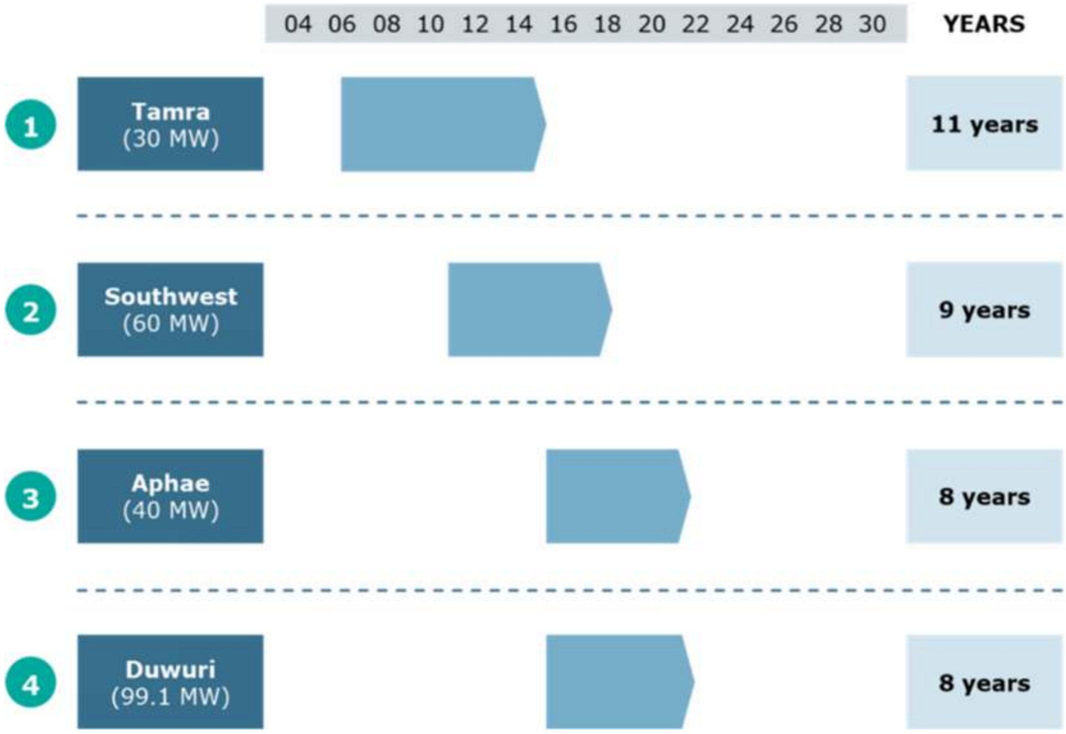


Figure 2-5 Development timeline from acquiring EBL to COD of four selected projects

Delays have occurred due to the high number of permits required and sometimes mis-matched goals of central and local authorities. Stakeholder engagement for this study also indicated that the opposition of strong stakeholder groups such as fisheries and women divers[1] has also delayed offshore wind development.

Despite the governmental efforts and policy plans made, stakeholders consulted for this study indicated that the Korean offshore wind developers still experience time consuming procedures for permitting and acceptance of offshore wind initiatives. Currently, permit applications must be submitted to multiple ministries (MOTIE, MOE, MOF and their affiliated organizations) resulting in uncertainties for the project developer. If the developer is not successful in realizing the project, it still must bear the costs of the entire failed development process.

2.2.2 Development incentives and risks

In order to enable a build-out of offshore wind, the economic incentives available to project developers must be balanced with the risks the developer must take in the market. If the risks are too great in relation to the economic incentives, project development will stagnate as developers decide that the risk is not worth the potential return. As a consequence, the wind build-out will stagnate as well. This section discusses the incentives and risks

[1] *Women divers (Haenyeo) practice a traditional method of earning their livelihood by harvesting sea food by hand*

for project developers in Korea as compared to those in Europe.

Korean development incentives

Renewable Energy Portfolio Standard

The Renewable Energy Portfolio Standard (RPS) is a Korean scheme to oblige energy suppliers to supply more than a certain minimum percentage of energy from renewables or purchase RECs corresponding to any shortfall in such RPS obligation. RPS was introduced in 2012 and obliges energy suppliers with an installed power generation capacity exceeding 500 MW (excluding renewable energy facilities) to supply renewable energy corresponding to a certain percentage of their total power generation [12]. It is designed so that if obligators fail to meet the initial targets, which are 9% of total power generation in 2021 and up to 10% in 2022, they are required to pay penalties by 150% of REC standard price. According to the amendment made on 20th April 2021 and effective on 21st October 2021, the upper limit of mandatory amount of renewable energy supply was increased to 25%, and actual target will be set on a yearly basis. Hence, the renewable energy target is expected to keep increasing.

Renewable Energy Certificates

Renewable Energy Certificates (RECs) are designed as a market-based instrument to provide an economic incentive for electricity generation from renewable energy sources in Korea. RECs use 1 MWh as their reference unit, and the quantity of RECs is differentiated by applying weights depending on the power generation method even if the same amount of electricity is supplied. Under the RPS and REC, the total income for the power generation from offshore wind energy is a combination of wholesale System Marginal Price (SMP) of electricity and the sale of REC price. Figure 2-6 displays the temporal trends of SMP trading prices from 2015 to 2020 [13], and Figure 2-7 shows the temporal trends of REC trading volume and mean trading price during the same period [14].

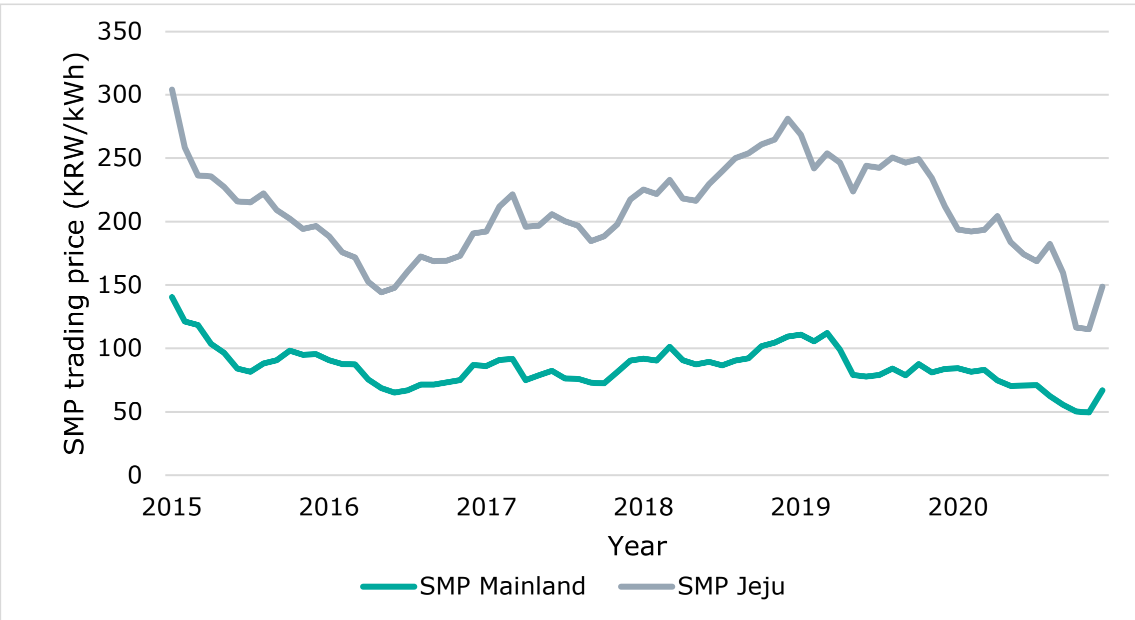


Figure 2-6 Temporal trends of SMP trading price (2015-2020) [13]

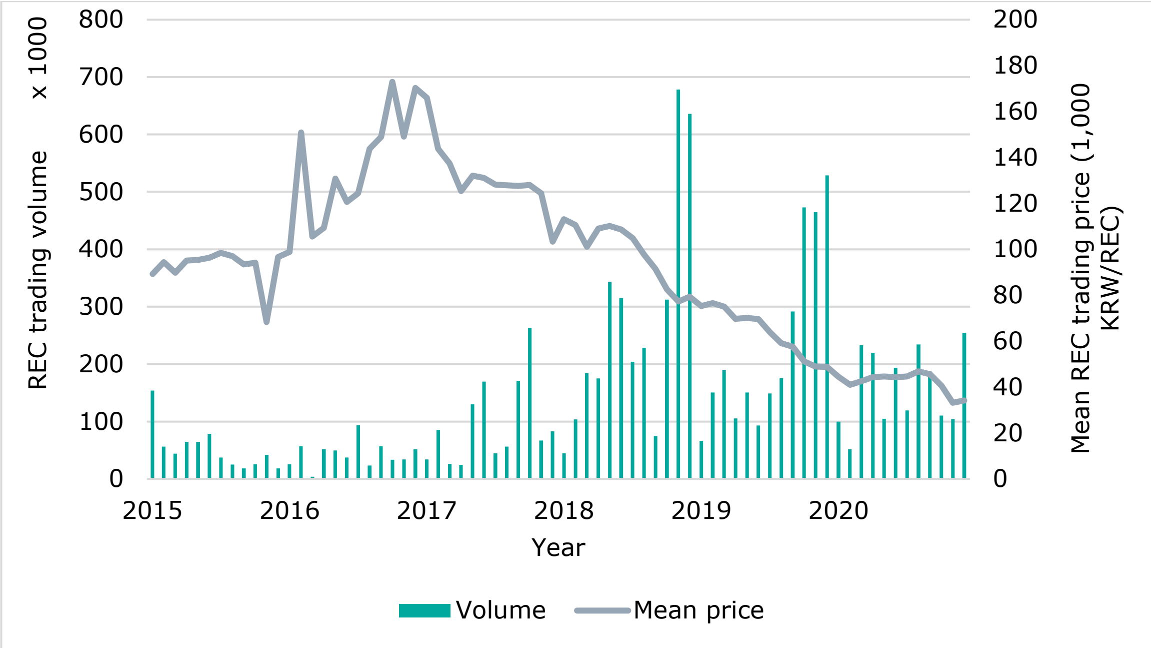


Figure 2-7 Temporal trends of REC trading volume and price (2015-2020) [14]

The REC allocated to a specific project is multiplied by REC weight factors. The weight factors are estimated by the straight distance between the closest coastline with a KEPCO substation and the center point of WTG closest to the coastline (so-called Connecting Distance), and it is in a range from 2.0 to 2.5 or more.

In the current RPS, power companies purchase electricity produced by offshore wind businesses at a fixed price and the fixed price is the sum of SMP or wholesale electricity price and REC price.

As shown in Figure 2-7, the REC market price was around KRW 173,000 as of May 2018, but since then it has continued to fall, recording the lowest price at around KRW 33,000 per 1 REC in November 2020. Although it is not verified what the exact reason is of this decline, stakeholders indicated that this REC price decline is mainly caused by:

- the increase of renewable energy supply (see REC trading volume around 2019 in Figure 2-7) and
- the wide range of generation types recognized as renewable energy (thermal generation using a mixture of coal and wood pellets is recognized as renewable energy)

Due to this decline, developers are experiencing difficulties with the economic feasibility for offshore wind. Among stakeholders, the details of REC regulations are expected to change once every three years, and 2021 is the year of revision.

Korean RE100

Emulating a global initiative bringing together the most influential businesses committed to 100% renewable energy (also known as RE100), MOTIE is planning to introduce the Korean RE100 (K-RE100) initiative in 2021. Electricity consumers who use renewable energy register a renewable energy application with the Korea Energy Agency to be recognized for their use of renewable energy. There are 5 ways to be recognized as renewable energy consumers or producers [15]:

- Green Premium: scheme allows electricity consumers to pay an additional green premium and

receive a Renewable Energy Use Confirmation
- REC purchase
- Third-party Power Purchase Agreement
- Equity investment
- Self-generation

Korean development risk profile

As the Korean offshore wind industry is still at the beginning of its development, various risks in development have been identified from the results of stakeholder engagements interviews.

Key risks are related to the current development procedures as described in Section 2.2.1. Prior to permit application, costly early-stage investments must be made by developers in Korea. The initial investment costs for metocean studies and engagement (or even compensation) of wind farm stakeholders which cost millions of Euros must be fully borne by developers. Due to the scattered permitting process many offshore wind projects are delayed, resulting in increased costs and uncertainty with regard to the return of investment. The project is only secured once the power purchase agreement is signed and finances are secured, but this step comes very late in the development process, adding more risk to the project developer.

In addition to the permitting uncertainties and the high early development costs, one of the requirements to acquire the necessary permits is that nearby residents' consents must be proven. Stakeholder consultation for this study has indicated that this consent is difficult to prove and many projects are suffering from local resident's opposition, resulting in delays.

As the Korean electricity grid is not yet optimized for renewable energy sources, developers do not have certainty that a grid connection for their projects will be provided in time. Relevant authorities for the required grid optimizations are working to resolve this constraint, but further governmental discussions and consultations are required, which is considered time consuming. This also increases the risks on delays for offshore wind projects.

Constraints in contracting foreign wind turbine manufacturers, also known as original equipment manufacturers (OEM), are experienced by developers. Many stakeholders have indicated that foreign OEMs are strongly preferred, as the project business case cannot sustain the additional risk posed by domestic OEM's lack of track record. Unclear expectations regarding local content are recognized by many stakeholders as constraint to enter the Korean market. Stakeholders agree that certain local content expectations in order to obtain a power purchase agreement exist, but these expectations are not written down. This increases the uncertainty of the project until very late in the development process. The uncertainty surrounding this topic was a recurring theme in stakeholder consultations for this study.

Korean overall profile

Based on the incentives and risk discussed above, the current risk profile for developers of offshore wind in Korea is considered imbalanced. The main development risks are a lengthy and unreliable permitting process, lengthy and uncertain resolution processes for local resident's opposition and barriers to using mature foreign turbine technology, in the form of implied local content expectations. The issue of permitting processes and handling of residents' opposition is addressed by the Green New Deal, which seeks to simplify permitting and licensing process. The implementation of these plans would contribute significantly to reducing permitting risk for developers.

On the incentive side, the government has implemented various measures to the market to encourage and support developers to invest and participate in offshore wind business, but they are still insufficient, and many institutional weaknesses can be pointed out. On the other hand, declining REC prices are a potential risk factor. The REC risk may be addressed in the coming 2021 revision.

European development incentives

In Europe, feed-in tariffs (FIT) are the most widely used means of accelerating investment in offshore wind. There are the two most common FIT policies which are the fixed FIT and the feed-in premium, which can be respectively considered to be independent of or dependent on the market price for electricity. Table 2-3 presents details of government subsidy systems and compares the government incentive schemes for offshore wind of Korea, the Netherlands and Denmark.

Table 2-3 Government subsidy system of offshore wind and comparison

Country	Korea	Netherlands	Denmark
Subsidy type	RPS	Stimulering Duurzame Energieproductie, Windenergie op Zee (SDE+ Offshore Wind); no subsidy since 2018 and no floor price guaranteed	Contract for Difference (CfD)
Options	REC	Sliding Feed-in Premium	Sliding Feed-in Premium
Subsidy period	Lifetime	15yrs + 1 year banking	50,000 full-load-hours (corresponding to approx. 11-12 years of operation depending on the site and the technical solution)
Auction	-	+	+
Tax production credit	+	+	+

Subsidy and development rights are granted through a competitive tender procedure in which companies bid for offshore sites. In this tender, permits to construct and operate the wind farm are granted simultaneously. Tender participants have to demonstrate that the bid is technically and financially feasible on the tender amount at the lowest costs per kWh included in its bid.

The described approach significantly lowered development time and cost for the developers. The Hollandse Kust Zuid I & II tender (700 MW) was awarded without subsidy grants in 2018. Additionally, the Hollandse Kust Zuid III and IV (760 MW) and the Hollandse Kust Noord (759 MW) projects were awarded in 2019 and 2020 without any subsidies. [16, 17, 18] In all of these projects, the cost of grid connection, the permitting and all soil investigations is covered by the Dutch government.

European development risk profile

In Europe, the levelized cost of offshore wind energy has been strongly reduced in the past years. The implementation of a one stop shop for permitting, the implementation of competitive tender schemes, improved economics of offshore wind due to wind turbine sizes and a matured supply chain can be considered as the main drivers for the decreased cost of energy. This has resulted in a reduced risk for project developers.

However, because many decisions in project development are made by governmental authorities, developers have limited liberties in project planning. The project size and development areas of offshore wind farms are selected by the authorities, developers can hardly discover new business opportunities and the industry and market sizes are strongly determined by the institutional circumstances. Also, smaller developers cannot participate in tenders for offshore wind due to the strict criteria for experience in offshore wind and capital position.

The main risk for developers in Europe is the fact that the project business cases are set based on their bid prices. If construction costs exceed their expected contingencies or if revenues from PPAs are lower than expected, financial feasibility of the project is likely to decline sharply.

European overall profile

Based on the incentives and risk discussed above, the current risk profile for developers of offshore wind in the Netherlands and Denmark is considered balanced. The developers still face project risks, but primarily the ones that are most directly under their control.

On the incentive side, incentives offer investment certainty by limiting the potential revenue downside, although in the Netherlands there is no guaranteed lowest energy price mechanism in place. This balanced risk profile in combination with a mature supply chain, has been successful at quickly bringing down the cost of energy.

2.3 Summary

Since 2017, several plans have been published by the Korean government which form the Korean policy regarding offshore wind. The common goal of all these plans is to increase energy from renewable sources and to expand the offshore wind power capacity from the current operational offshore capacity of 124.5 MW to 12 GW by 2030.

Europe, in particular Denmark and the Netherlands, were early adopters of offshore wind and have developed their own offshore wind development policy through experience. The European experience has shown that complexity of permitting processes for offshore wind directly correlates with longer permitting times and increased risk for project developers. To simplify licensing and permitting procedures and reduce risk, the Dutch and Danish governments have introduced a 'one-stop shop' type of licensing process. Implemented by the Netherlands Enterprise Agency (RVO) and the Danish Energy Agency (DEA), developers can significantly reduce administrative procedures and accelerate offshore wind energy development and distribution. These two government agencies are responsible for spatial planning, site selection, pre-site investigation, licensing, environmental impact assessment, grid connection and related infrastructure construction.

Although Korean governmental plans are promising to establish a friendly environment for investments in offshore wind, only 4 offshore wind farms, with a total installed capacity of 124.5 MW were realized by the end of 2020. Another 42 offshore wind projects with a total development capacity of about 7.7 GW had acquired the necessary very first license to produce electricity. These projects are mainly being developed by Korean private development parties, or by consortia of Korean private and public parties.

The government is promoting the introduction of local government-led siting, consideration zones and simplification of licensing procedures, and increased residents' acceptance through Korea's offshore wind collaboration plan to achieve a target to build 12GW of offshore wind by 2030.

Despite the government’s ambition and efforts until now, the current developer’s risk is considered high compared to the European development environment.

The Korean government introduced their plans to establish a new organization for one-stop permitting, but the establishment is being delayed and discussions are still ongoing due to the differences in positions among ministries. In addition, project developers still experience opposition from the local fisheries and women divers’ groups and are suffering from high investment risks due to uncertainty about permitting, early development investment and local content expectations. Increasing risks and costs in the installation and the operational phase are also expected due to involvement of inexperienced contractors.

In Korea, the burden of early-stage development costs is put solely on project developers. Uncertainties regarding the grid connection is another risk, as further discussion and consultations are needed to improve the electricity grid and make is suitable for a large share of renewable energy.

The economic feasibility of the licensed offshore wind projects is under pressure due to decreasing REC prices as a result of an increasing share of sustainably produced energy by sources other than offshore wind. Finally, unclear local content expectations form a big hurdle for foreign wind turbine manufacturers to commit to the Korean market, resulting in less competition and generally higher pricing for wind turbines, due to limited competition.

In order to reduce the developer’s risks and boost the industry, this study recommends several improvements on policy environments to Korean policy makers:

- Clear and stable long-term roadmap: the masterplans introduced are very extensive but more elaborated and specific plans are needed
- Introducing a 'one-stop shop' permitting process: to avoid longer permitting processes and resulting increased risks and costs
- Government taking risks: to reduce developers’ risks in early-stage development, site selection, permits, grid connection and stakeholder involvement need to be taken by the government
- Formal laws and regulations for stable and expectable financial incentives to relieve pressure on developers caused by REC price decline

Photo: GE

3

SUPPLY CHAIN

3 Supply chain

In addition to a favorable policy environment, the build-out of offshore wind energy in Korea will require an adequate supply chain to manufacture, install and operate the wind farms. Accelerating offshore wind power in Korea hinges on the industry's ability to establish a sustainable and effective supply chain. This supply chain will determine not only the speed of adding offshore wind capacity, but also its cost.

This chapter provides an overview of key components of the offshore wind supply chain, and its key players in Europe and Korea. It is not meant to give a complete overview of all individual companies involved. Additionally, this chapter describes short-term (before 2026) and mid-term (between 2026 and 2030) outlooks for Korean supply chain and introduces two supply chain scenarios to find efficient ways to enable the delivery of 12 GW of offshore wind farms in Korea.

3.1 Supply chain components

An offshore wind farm is a whole system of interconnected parts, from the onshore substation to the wind turbines at sea. Figure 3-1 shows the typical components for a bottom-fixed offshore wind farm.

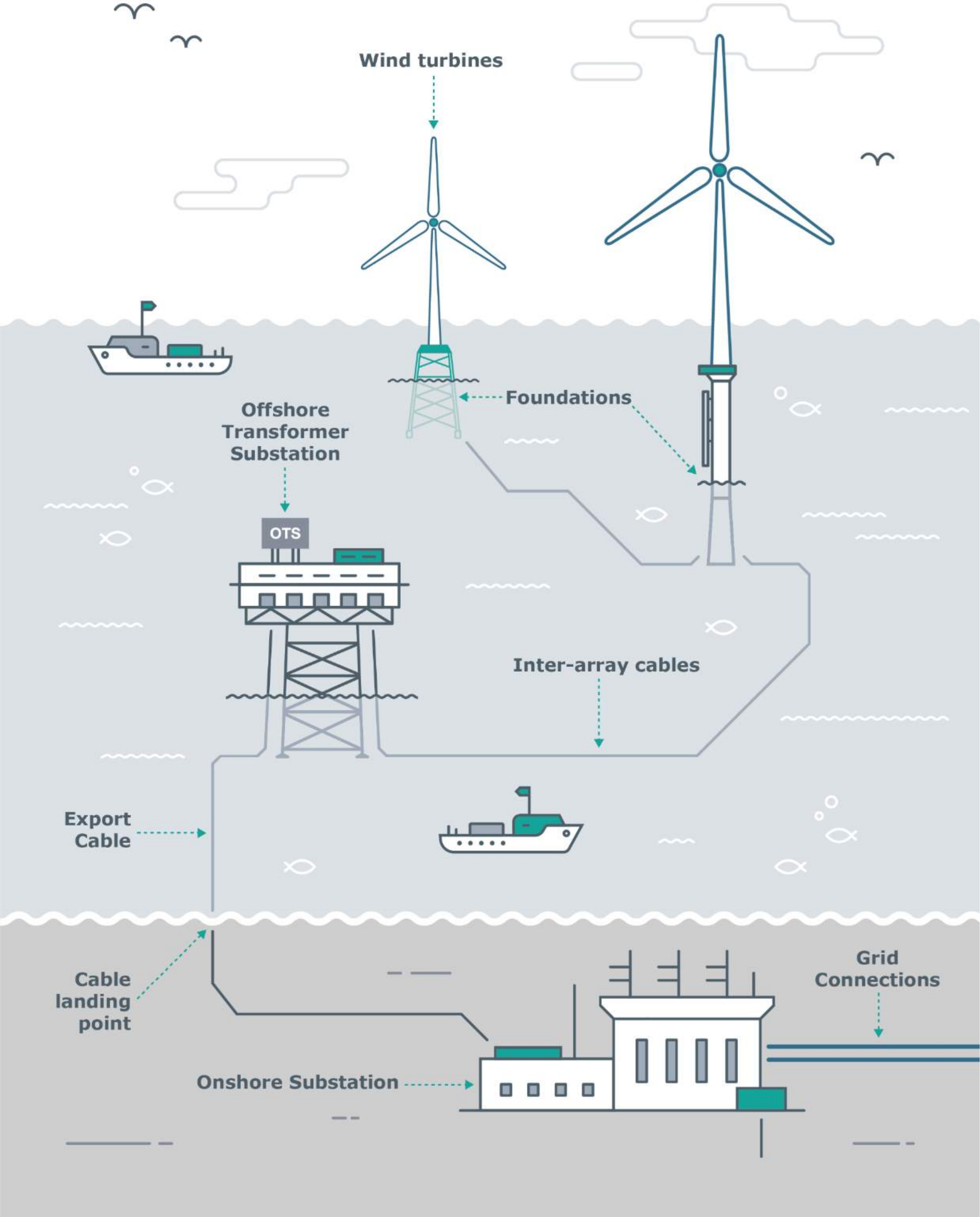
The components in the figure also represent much of the typical supply chain for an offshore wind farm. The wind turbines are the heart of the wind farm and they are supported by the balance of plant (BOP), which includes all infrastructure except the turbine. BOP includes:

- turbine foundations (commonly monopiles or jackets)
- transition pieces between foundation and turbine
- inter-array cabling (medium-voltage cabling within the wind farm)
- offshore substation
- export cabling (high-voltage cabling connecting the offshore substation to the onshore substation)
- onshore substation
- any additional elements needed for grid connection onshore

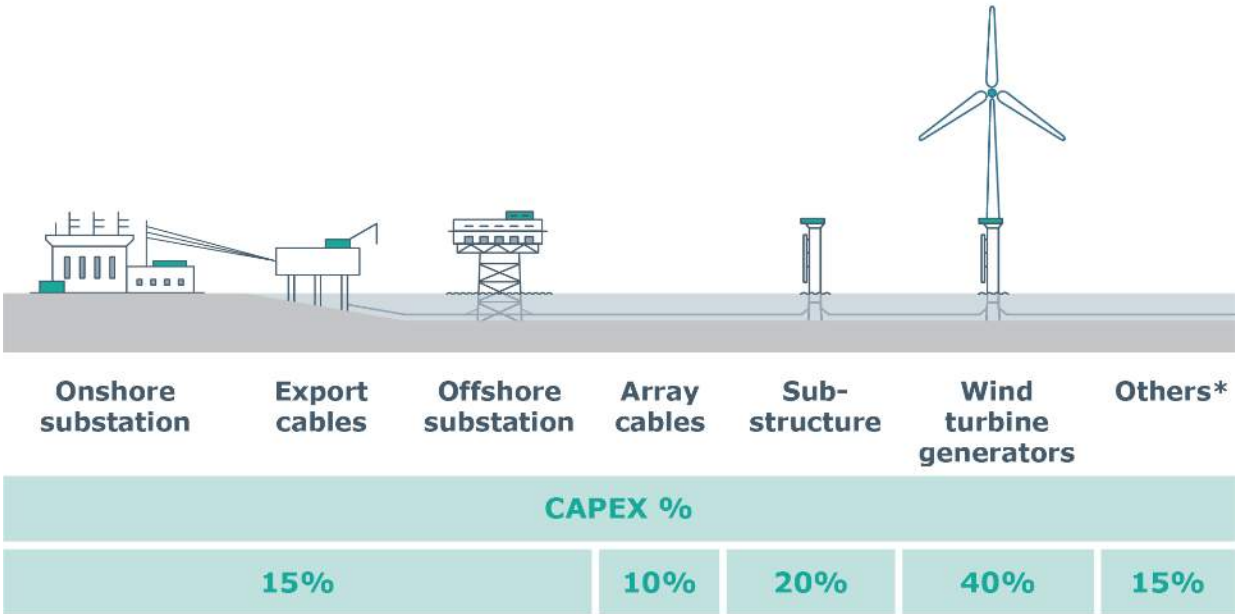
In addition to the manufacture and supply of these components, they must also be installed and serviced by specialized vessels, which can also be seen in the figure. Similar vessels are later employed for the decommissioning of the wind farm at the end of its lifetime.

The components are slightly different for floating offshore wind farms. While bottom-fixed monopiles are rammed into the seabed by specialized vessels, floating foundations only need to be moored in place after being towed out to their destination. Similarly, floating wind farms do not generally require specialized turbine installation vessels for the installation of the turbine at sea. The turbine is simply mounted on the floating foundation at port and towed out to the wind farm fully installed.

Figure 3-1 Components of a typical bottom-fixed offshore wind farm (source: COWI)



It is important to have an adequate supply chain across all stages and systems to deliver projects on time within budget. Many factors in the development phases contribute to the costs. Figure 3-2 displays a capital expenditures breakdown of a typical offshore wind farm. The percentage number shown in this figure is indicative. There can be a large variation per site conditions, construction methods, technical levels and supply chain capabilities.



*Includes internal & external resource costs, insurance, O&M facilities & equipment, contingency

Figure 3-2: Overview of CAPEX components and their share of total CAPEX [19]

An offshore wind project is highly capital-intensive. Figure 3-2 shows that most costs of offshore wind farms are attributed to supply and installation of the wind turbine and BOP. These categories will be further discussed in the coming sections, as well as project development. Project development costs themselves are a small percentage of wind farm CAPEX, but the development stage has a disproportionately large impact on the costs of the rest of the wind farm.

3.1.1 Project development

Offshore wind is a multi-disciplinary industry and project development requires extensive knowledge, skill and experience.

Developers with sufficient knowledge of what is required and how the projects should be implemented and maintained are well positioned to successfully realize their project and to satisfy lenders and licensing authorities.

Typical phases of an offshore wind project can be described as follows:

- Acquisition of site
- Feasibility study
  - Wind measurements
  - Calculating potential yield of wind farm
  - Preliminary wind turbine selection
  - Basic foundation design
  - Layout optimization
  - Grid connection options
  - Cable route determination
  - Financial feasibility
- Environmental Impact Assessments
- Permitting
- Consortium formation

- Contracting (wind turbines, BOP, construction and installation)
- Power Purchase Contracts
- Financing
- Construction management
- O&M management

In all of these phases, experienced developers, consultants and engineers are of crucial importance.

Foreign supply

As Korea has announced their ambitions to expand their offshore wind capacity up to 12 GW by 2030, many global developers are expanding their activities to Korea.

Ørsted announced their plans for Korean offshore wind projects with a capacity of up to 1.6 GW off the Incheon coast. Northland Power announced their agreement signing to acquire Dado Ocean Wind Farm, a development company with several offshore wind development sites near Chodo, South Jeolla province. Green Investment Group and Total SE have made agreements to jointly develop an initial portfolio of five offshore wind projects of 2.3 GW in Korea - three in Ulsan totaling 1.5 GW and two in South Jeolla Province totaling 800 MW [20, 21, 22]. German developer wpd is currently working on a "pipeline of over 1 GW potential onshore/offshore projects" with undisclosed local partners [23].

The City of Ulsan has attracted many major global developers to join their floating offshore wind ambitions, and signed memorandums of understanding with five consortia: (1) Munmubaram (Royal Dutch Shell and CoensHexicon), (2) Copenhagen Infrastructure Partners and SK E&S, (3) Green Investment Group, (4) KFWind (WindPower Korea, Principle Power, EDP Renewables, Aker Solutions and ENGIE); and (5) Equinor, Korea National Oil Corporation and the Korean power company Korea East-West Power [24, 25, 26, 27].

In addition to developers, international consultants, engineering companies and research institutes play their role in Korea.

Pondera Consult is an international renewable energy consultant based in the Netherlands and provides owner's engineering services to Jeju Hanlim Offshore Wind [28]. K2 Management is a Danish-based international renewable energy consultant and work as the owner's engineer for Taean offshore wind [29]. COWI is a Danish engineering and market advisory consultancy with experience in offshore wind and an office in Korea. Aegir Insights provides market intelligence for global markets from their headquarters in Copenhagen, Denmark.

Deltares is an independent institute for applied research, especially in the field of water and contributes to offshore wind industry as well in a form of applied research and consultancy projects [30]. KCI the engineers offers an in-depth engineering and design services for offshore wind, [31] and geo-data specialist, Fugro provides design and installation consulting of foundations [32]. Dutch engineering company Iv-Groep has some track record in offshore substation design [33].

Korean supply

In total, 42 offshore wind projects had acquired an EBL as of March 2021 [6]. Among these projects, the largest is Taean Offshore wind with a total capacity of 504 MW and Korea South-East Power, which will be developed by a special-purpose vehicle formed by Korea Western Power and Doosan Heavy Industries. At a provincial level, South Jeolla offshore wind power complex is the largest with a total capacity of 984 MW of offshore wind projects that will be built in three-phases by KEPCO, Hanwha E&C, and SK E&S. Hanlim Offshore Wind Power (100 MW) is the only offshore wind power project that may start construction this year. This project is developed by a special-purpose vehicle consisting of KEPCO, Korea Midland Power, and KEPCO E&C. Considering the current permit process, the following wind farms are preparing to start construction in the coming years:

- Anma Offshore Wind Farm (528 MW) under development by Anma Offshore Wind Power (JNDC- KWC-KHNP-HEC consortium)
- Jeonnam Offshore Wind Power (96 MW) under development by SK E&S
- Nakwol Offshore Wind Power (358 MW) under development by Myungwoon Development
- Geumil offshore wind power (200 MW) under development by Korea South-East Power
- Shinan Ui Offshore Wind Power (396 MW) under development by Hanwha E&C

For a list of developers who have acquired EBL, refer to Appendix A.

In the offshore wind industry, various engineering services are required such as site condition review, economic feasibility analysis, designing and technical advisory services to the project lenders. Blue Wind Engineering, Windetect, Yusuk Industry, Dream Engineering, Hansae Korea, K-wind, Kepco E&C, KLEM, Saman Engineering, Yooshin Engineering, and Dowha Engineering are providing engineering services for offshore wind power development.

3.1.2 Wind turbine

In the supply chain for offshore wind, the wind turbine supply contract and O&M contracts are some of the biggest contracts closed by the developer. Offshore wind turbines continue to grow in size: the average rated capacity of a turbine installed in 2020 in Europe was 8.2 MW, and the average size expected to be installed in 2022 is 10-13 MW. GE Renewable Energy launched a 12-14 MW turbine in 2018 [34]. Siemens Gamesa recently unveiled a 15 MW wind turbine, which will be commercially available from 2024 [35]. The latest turbine announcements are for rated capacities in the 15 MW range [34, 35, 36]. These developments are powered by the strong winds of Europe's North, Baltic and Irish Seas, where most European wind farms are installed at average wind speeds of over 9-10 m/s at 100 m [37].

However, the wind speeds in the Korean peninsula are significantly lower, commonly between 6.5-8 m/s at 100 m hub height [37]. These low wind conditions would be best served by a turbine with a large-diameter rotor matched with a comparatively small generator, as is seen in onshore wind turbine for low wind speeds.

A wind turbine consists of the following major components:

- Blades
- Nacelle
- Low speed shaft
- Gearbox
- High speed shaft
- Generator
- Yaw & Pitch drive & bearings
- Tower flange

Because a wind turbine is a very comprehensive equipment with the above components, it is also desirable to consider synergy through component-specific cooperation between foreign suppliers and Korean suppliers. Through this component-specific cooperation, local content can be increased.

Foreign supply

The European offshore wind market is dominated by three globally active OEMs: MHI Vestas Offshore Wind (Vestas), Siemens Gamesa Renewable Energy (SGRE) and GE Renewable Energy (GE).

GE launched a 12-14 MW turbine with its largest capacity in 2018, and Siemens Gamesa recently unveiled a 15 MW wind turbine, which will be commercially available from 2024 [34, 35]. Vestas offers the V236-15.0 MW which is scheduled to begin serial production in 2024 [36].

For the low wind speeds of the Korean market the global OEMs are expected to mostly offer their large turbine models with large rotor-diameter and de-rate the generator to around the 10 MW level. In addition to the resulting power curve advantage discussed in section 4.1.1 , this will likely result in tower and foundation design optimizations, resulting in slightly lower costs. Due to relatively low wind loads on the wind turbines, design lifetimes longer than 25 years can be expected, however this is not unique for low wind speed regions only. Innovations like smart monitoring using extensive condition monitoring systems and lidar wind measurements will also be used in future to prolong the operational lifetimes of a wind farm.

Danish companies such as KK Wind Solutions and Mita-Teknik provide wind turbine control, subsystems and SCADA systems, respectively. LM Wind Power and Welcon respectively, offer blade and tower for offshore wind turbines [38, 39, 40, 41].

The turbines produced by Chinese OEMs such as Goldwind, Shanghai Electric, MingYang and Envision are widely and almost exclusively used in the Chinese market. The rated capacities of the Chinese wind turbines range from 3 to 8 MW [42, 43, 44, 45].

Korean supply

Three domestic Korean OEMs are active in the offshore wind market: Doosan Heavy Industries (Doosan), Unison and Hyosung.

Of these OEMs, Doosan is the only one known to currently manufacture offshore wind turbines. Doosan's 3 MW DS3300 model is the only offshore turbine which has been supplied for commercial projects with a total track record of 30 units [46].

Doosan acquired the design and manufacturing licenses of a 5.5 MW wind turbine from Hyundai Electric in 2017, which currently is commercially available as the Doosan WinDS5500. In 2020, it was announced that in total 18 units of Doosan's 5.5 MW model were selected to be deployed within the Jeju Hanlim offshore wind project [47].

Doosan began development of an 8 MW offshore wind turbine in 2018. The turbine design focusses on relatively low wind speed areas such as Korea and other parts of Asia. The project is government-backed, and it aims to commercialize the wind turbine in 2022 [48].

Unison is a specialized company in wind turbine and has a significant track record for onshore turbines. They recently announced their intent to develop a new offshore wind turbine: the Hemu-X 10 MW. Unison aims to produce prototypes from 2021 and commercialize its first offshore wind turbine in 2023 [49].

Though Hyosung's 5 MW prototype was installed at a test site in 2014 and certified in 2015, the OEM has not made any known recent sales or announcements to develop further activities in the offshore wind market since then [50].

The Korean company CS wind is leader in production of towers for all global wind turbine manufacturers and some Chinese OEMs. CS wind serves 60-70% of the global market outside China [51].

With regard to wind turbine component, Korean suppliers have relatively good track records. Haisung TPC succeeded developing 3 MW class wind power generation system yaw & pitch drive, and a total of 21 units have been delivered and additional supply contracts are in progress [52]. Taewoong [53], a specialized forging product company, has succeeded in developing yaw bearings with the support of the Korea Institute of Energy Technology Evaluation and has actively promoted overseas market entry currently stably selling products to GE and Vestas. PSM (Pyeongsan) [54], Taewoong, Yonghyun BM, Hyunjin Materials [55], Dongkuk S&C [56], and Unison produce and export major parts that undergo steel forging and welding processes such as main shafts, tower flanges, towers and bearings. For large blades, KM has the experience of manufacturing wind turbine blades of 3 MW, 5.5 MW and 7 MW, and Human Composite [57] is recently undertaking an order contract for the production of large blades. Human Composite, the only blade manufacturer in Korea, produces from 2 MW class onshore blades to 5 MW class offshore blades. Since 2017, they have been producing 3 MW class (IEC Class III) blades with ultra-light carbon fiber and supplying it to the Southwest Sea offshore wind power demonstration project.

3.1.3 Balance of plant

The balance of plant contracts covers the engineering, procurement and installation of all infrastructure except for the wind turbine: foundation, cabling, offshore transformer substation and onshore substation. The turbine foundation forms a major part of BOP investment costs. The selection of the foundation type depends on the water depth, seabed conditions, wave and tidal loads, turbine specific static and dynamic loads, but also on the local manufacturing and installation capabilities. The foundation has traditionally been fixed to the seabed, but floating foundations are currently being introduced. In Korea, floating foundations can be considered in Ulsan, East Sea.

For bottom-fixed foundations, the monopile concept was first introduced in the Lely offshore wind farm project in the Netherlands in 1994. After then, this substructure has been applied in more than 80% of all European offshore wind projects due to the sandy seabed and relatively low water depth in Europe [58].

Jackets are typically selected in cases when it is difficult to apply monopiles due to deeper water depths, special seabed conditions or due to domestic supply chain constraints. Their commercial use for offshore wind turbines started in 2006 with the Beatrice project in Scotland [59]. Jacket production requires more laborious fabrication and maintenance compared to monopiles. Additionally, more space on deck is required while being shipping out to sea. Furthermore, the positioning of jackets on the exact location on the seabed is a delicate process.

Offshore wind turbines are connected to offshore substation(s) through medium-voltage inter-array cables. The substation collects, steps up and exports the power generated by the offshore turbines via submarine cables. The export cable typically passes through an onshore substation, before reaching the grid connection point.

Foreign supply

For foundation (monopile and jacket) fabrication, Sif, Lamprell, Navantia-Windar Consortium, Bladt and EEW are European and global leading companies. Eiffage Smulders is also an international steel construction company contributing to offshore wind. Gusto MSC is jointly developing a floating foundation, Tri-Floater with Korean companies, Halla Wind Energy and Korean Maritime Consultants (KOMAC) [60, 61, 62, 63, 64, 65, 66].

JDR Cable Systems, TKF Group, Nexans, Prysmian Powerlink and NSW Technology are the dominant players in inter-array cables market. Prysmian, NKT Group, Nexans, Hellenic Cables and LS Cable & System are the major players in export cables market. [67, 68, 69, 70, 71, 72]. LS Cable & system is not in this figure due to varying order intakes, but LS Cable & System took a share of 9% of the export cable market in 2019 [8]. For offshore substations, the majority of global market shares are held by ABB, Siemens, Alstom and CG Power [73, 74, 75, 76]. Hereema Fabrication Group and HSM Offshore are Dutch steel fabrication companies with track records in substation fabrications. Semco Maritime also provides substation design and construction with a track record of more than 20 projects [77, 78, 79].

Korean supply

Jacket foundations have been used for all offshore wind turbines currently in operation in Korea. Stakeholder engagement indicates that this use of jacket rather than monopile foundations was due to the lack of domestic monopile supply capability at the time of wind farm installation. About 400 tons of post-piled jacket structures were used in each of the foundations for Doosan's 3 MW offshore wind turbines [80]. Jackets fabricated by Hyundai Steel Industry were used in most projects installed in Korea. Samkang M&T also manufactured and provided jacket structures for the Jeju Woljeong test site (1 unit) and Changhua Offshore Wind Farm in Taiwan (21 units) [81]. In Korea, no monopiles have yet been constructed and it is expected that smaller diameter monopiles could be domestically produced in the near future. Due to the high number of shipyards and the steel industry in Korea, production of monopiles in Korea can be considered as a natural step to take. However, larger turbines such as those available from foreign OEMs will require what are known as "XL monopiles," which have diameters of more than 7 meters. Developing domestic Korean capability for XL monopile production is expected to take some additional time.

For floating foundations, Samsung Heavy Industries and DNV GL have made an agreement to jointly develop floating wind technology, including floating foundations, and expected to supply floating technology into the market in mid 2020s [82]. Additionally, some other Korean companies like CoensHexicon are active in developing floating structures for offshore wind.

Hyundai Steel Industry manufactured an offshore substation which consist of about 600 tons of jacket structure and 980 tons of topside for the Southwest Sea Offshore Wind demonstration site [83]. Manufacturing and installation of onshore substations is highly influenced by local conditions, so in most cases, domestic companies are involved.

Korean submarine cable manufacturers are Taihan [84] which has a track record of supplying it to Southwest Sea Offshore Wind demonstration site and LS Cable & System which is one of the global market leaders.

Local companies that have track records of submarine cable installation are Haechun [85] which installed the cables at the Tamra

Offshore wind farm and export cables at the Southwest Sea Offshore Wind demonstration site and KOCECO [86] which installed inner-array cables at the Southwest Sea Offshore Wind demonstration site. KT submarine also offers submarine power cable installation and maintenance but has no track record for offshore wind.

3.1.4 Installation and commissioning

Over the lifetime of an offshore wind project, a variety of vessels and equipment perform activities varying from marine survey, foundation installation, turbine installation, substation installation and cable. There are three main activities in the installation and commissioning: turbine, foundation and cable installation. Special equipment is required for each of these disciplines, and Figure 3-3 shows examples of the related offshore wind farm construction vessels. Worldwide, there are 137 vessels available, out of which 82 are jack-up vessels and 55 are heavy-lift vessels, that have participated in offshore wind turbine installation work in 2020 [87]. Of these vessels, 61% are located in Europe and the remaining 39% are located in China, which are the largest offshore wind markets [87].

a) Towed barge

b) Shear-leg crane barge

c) Semi-submersible heavy lift vessel

d) DP2 heavy lift cargo vessel

e) Towed jack-up crane barge

f) Self-propelled jack-up vessel

Figure 3-3 Examples of offshore wind farm construction vessel [88]

Most offshore wind turbines are installed in five steps: tower in one single lift, nacelle in a single lift and then the three blades separately. It is important to consider installation vessels and equipment that are suitable for the site conditions and economically efficient. Vessel options can be divided into either wind turbine installation vessels or jack-up barges, and when jack-up barges are selected, tugboat, cargo barge, anchor handling tug supply are additionally considered according to their specifications.

Unlike turbine installation, foundation installation can be performed by a variety of vessels such as heavy lift vessels, crane vessels and jack-up vessels depending on the size, seabed condition, economic feasibility, etc.

Equipment for submarine cable installation can be largely divided into equipment for laying inter-array cables and export cables. Inter-array cable installation can apply two different approaches, the first is to apply a single lay and burial process using a plough and the second is applying a separate surface lay and subsequent burial approach using a jetting tool on a remotely operated vehicle. Because the export cable should be installed from the offshore substation to the onshore substation with a single cable without cable short circuit, it needs large vessels and, moreover, cable installation requires a higher level of technology and equipment than turbine or foundation installation.

Foreign supply

Currently, many equipment companies are developing jack-up vessels designed for the purpose of wind turbine installation. There are many players in this market such as DEME, Seajacks, Fred Olsen Windcarrier, Van Oord (MPI-Offshore), Jack-Up Barge, SEAFOX Jan de Nul, A2Sea, etc. [89, 90, 91, 92]

The heavy lift vessels, Innovation (DEME), Seaway Yudin (Seaway7), crane vessel Pacific Osprey (Swire Pacific Offshore) and Svanen (Van Oord) and jack-up vessels Aeolus (Van Oord) and Vole au vent (Jan De Nul) have performed monopile installation which is the most applied foundation type in Europe. There are many cases to use heavy lift installation vessels for installing monopiles with special equipment such as cranes, monopile grippers, Hydraulic piling hammers, etc. Some vessels which installed jacket structures are the crane vessels Reabiz, Giant 7 (Boskalis) and Taklift 4 (Huisman) and the jack-up vessels Victoria Mathias (Van Oord) [92, 93, 94, 95, 96, 97].

Regarding the availability of European contractors, there is a possibility of European companies entering the Korean market, but it highly depends on the size of the project. According to stakeholder engagement, European contractors are highly interested in the Korean market, but compared to the high demand for large projects in Europe and the US, potential smaller size projects in Korea are less attractive. Stakeholder engagement has shown there are two main perceived barriers to entry of the Korean market: (1) local content expectations; and (2) the possibility of construction with smaller equipment in the future. Therefore, it is expected that projects need to be of at least 500 MW capacity in order to attract global supply chain resources. Many of the existing offshore projects that hold an EBL consist of several smaller projects, which can be pooled into larger projects in order to increase attractiveness for developers and the offshore wind supply chain.

The leading supplier in submarine cable installation are Subsea 7 and major European EPC contractors, Boskalis and Van Oord have developed dedicated vessels for cable installation in their business area. Nexus, is the first cable-laying vessel from Van Oord, serving many offshore projects in Europe both for laying inter-array cables and export cables. Multipurpose vessels from Boskalis such as Ndurance, Ndeavor and Spirit are actively working on the market. [93, 95, 96] Danish offshore marine services provider, Maersk Supply Service operates a diverse fleet of modern vessels to support offshore wind operators. [98] Dutch marine contractors, Heerema Marine Contractors, Van Oord and SPT Offshore have a rich track record in transportation and installation of offshore wind turbines and is a leading offshore contractor for suction pile anchors and foundations, respectively. Royal IHC provides a wide range of installation solutions for offshore wind [99, 100, 101].

Korean supply

In Korea, a general-purpose jack-up barge with a crane was used to install the wind turbines of Tamra Offshore Wind. Hyundai Steel Industry developed the Challenger 1, a jack-up barge (5,500t) in 2016 and used it for the installation of wind turbines and foundation in the Southwest Sea Offshore Wind demonstration site. Samsung Heavy Industries has recently received approvals in principle for their low carbon emission wind turbine installation vessel, SLW-FUEL CELL from the American Bureau of Shipping, DNV, and Lloyd's Register. Samsung Heavy Industries was contracted with the construction of three wind turbine installation vessels (Pacific Osprey, Pacific Orca, Seajacks Scylla) for the European operators Swire Blue Ocean and Seajacks [102, 103, 104, 105]. No installation vessels for monopile installation are available in Korea so far and it is expected that the engineering and construction of dedicated vessels for modern offshore wind farm installation will take 2-3 years. This is mainly caused by long lead times for supplying the required heavy lifting equipment due to a large global demand for such heavy lifting equipment.

3.1.5 Operation and maintenance

Offshore wind farms typically have a 25+ years' operating lifetime and O&M provides service over the lifetime of a wind farm in order to minimize downtime and improve energy production.

The operation of the wind farm is managed at an onshore base near the port that meets its specifications. O&M staff monitors potential faults and errors through routines such as day-to-day workflow management, data gathering and remote analysis and report to the O&M site manager. Logistics management for maintenance services is also an important part, which includes vessels, personnel, specialist tools and spare parts. Maintenance is divided into planned and unplanned events and most of the planned work is to inspect offshore wind turbines and periodic replacement of worn-out systems and components. Special vessels such as jack-ups are required to replace major components such as blades or gearboxes. Wind turbine manufacturers generally offer long-term service contracts, so all maintenance during that period is carried out by the manufacturers. Therefore, manufacturers are responsible for the turbine maintenance work, but the BOP maintenance work can be carried out by domestic companies. Inspections and maintenance of foundations are carried out less frequently than turbines but require structural inspection on a regular basis because the mix of atmospheric, marine and biological corrosion can cause damage that is both expensive and difficult to repair. Submarine cables should be monitored for cable burial conditions by conducting periodic undersea surveys every few years.

Offshore wind farms are usually located in more windy areas far from shore to increase energy production proving challenges for vessels to undertake maintenance activities from an onshore base near the port. In large and remote offshore wind farms, service operation vessels (SOV) are used to carry out the maintenance tasks and remain at sea for long period with the crew lodging on board. In wind farms nearer to shore with relatively short travel time, less expensive crew transfer vessels (CTV) are used to support O&M activities from nearby O&M ports.

Wind farm maintenance is characterized by long-term work during the lifetime of the offshore wind farm, so the work can be carried out, typically by the OEM, through contracts with local companies providing possibilities for local involvement in the long-term.

3.1.6 Supplier summary & partnership potential

Supplier summary

The suppliers discussed in this section are categorized and summarized in the following tables. This overview should not be considered as a complete overview of all companies active in the industry, but rather a selection of major suppliers.

It is important to note that these suppliers have different maturity level in relation to offshore wind. This is illustrated in Figure 3-5- Figure 3-7 using icons shown below in Figure 3-4:

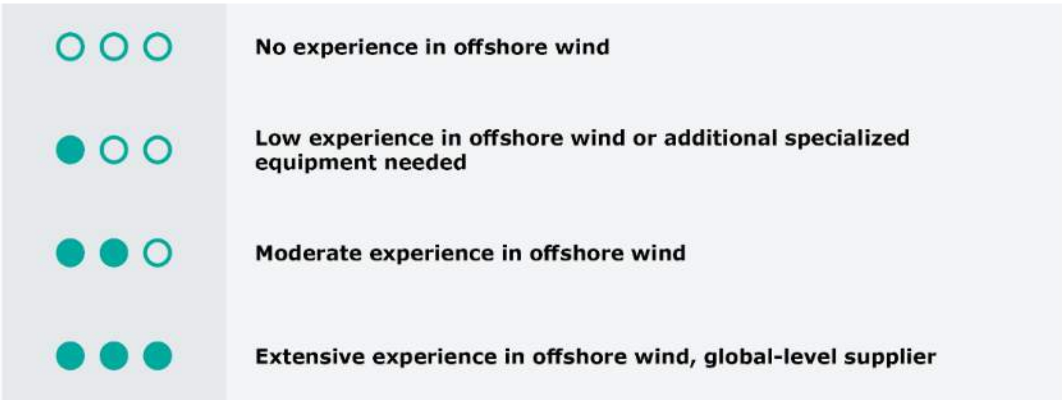


Figure 3-4 Maturity level indicators

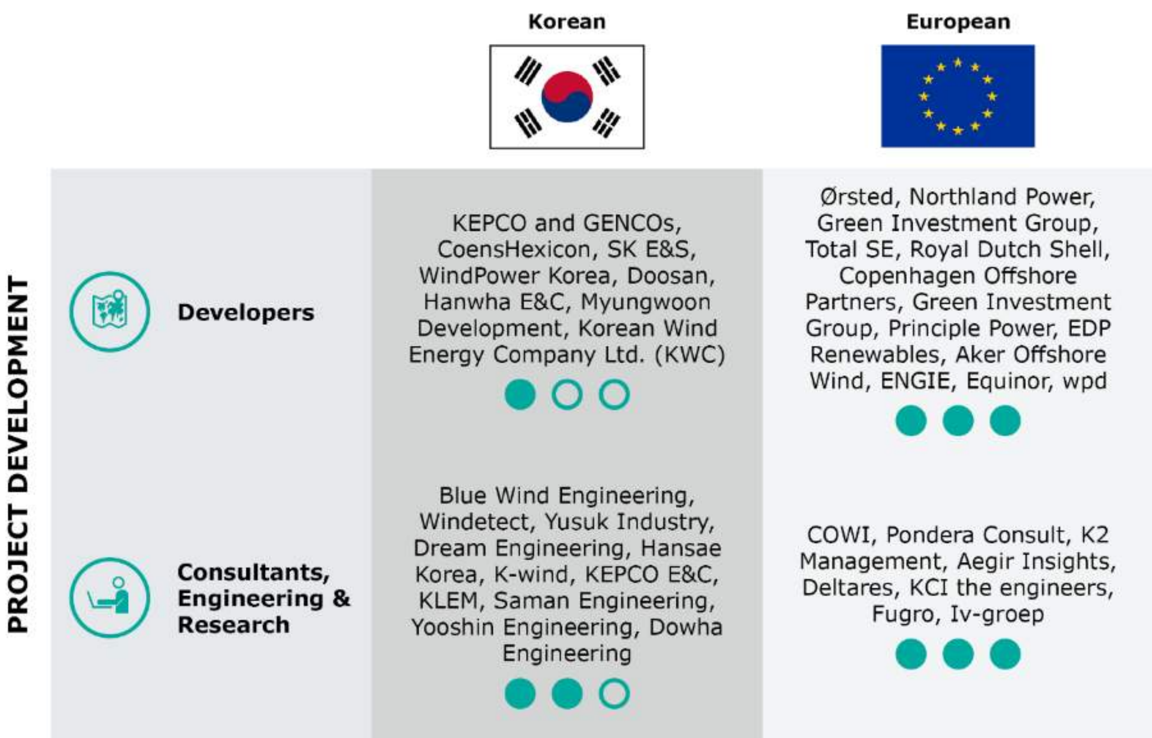


Figure 3-5 Selected major suppliers for project development in the Korean offshore wind market

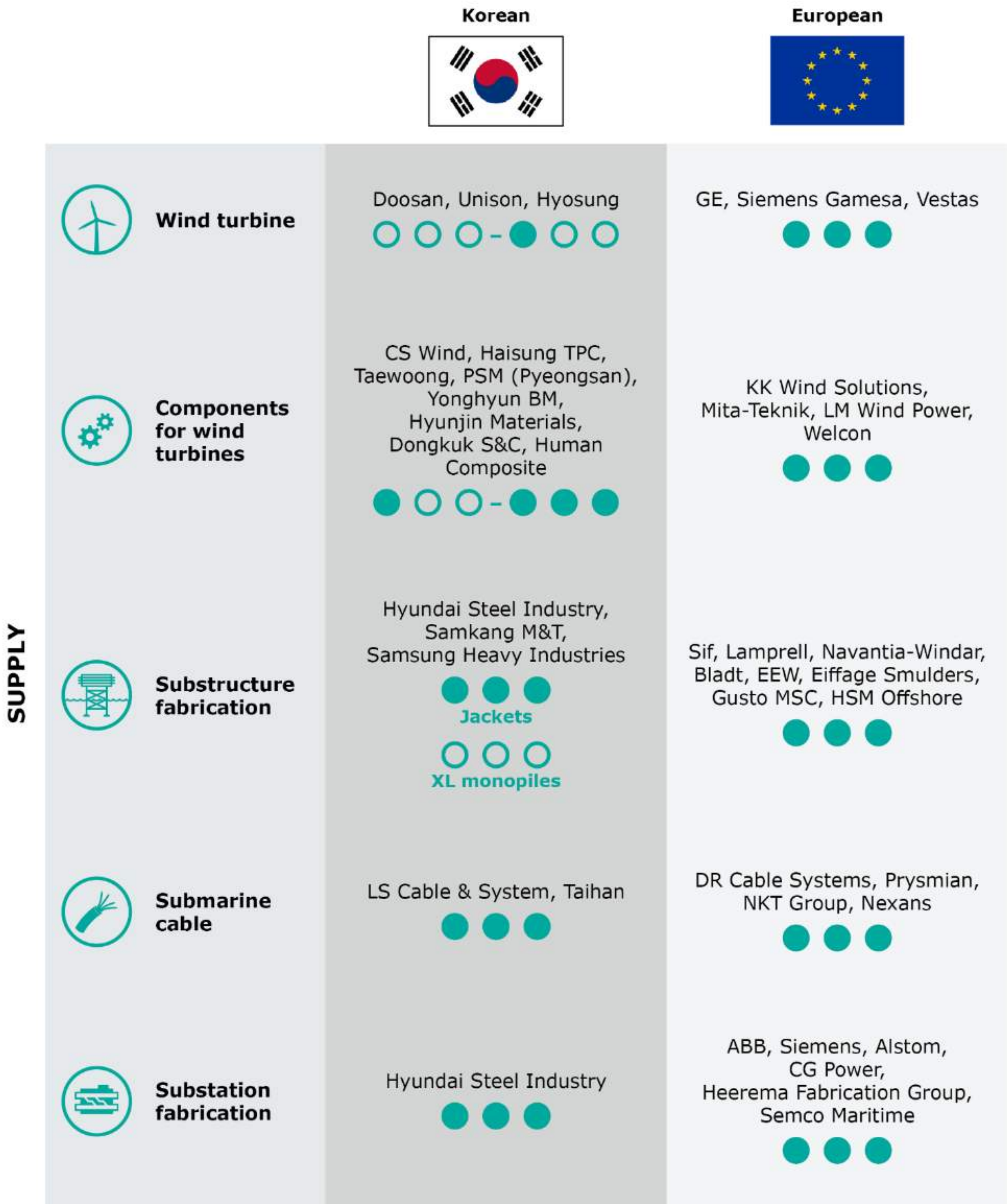


Figure 3-6 Selected major suppliers for fabrication in the Korean offshore wind market

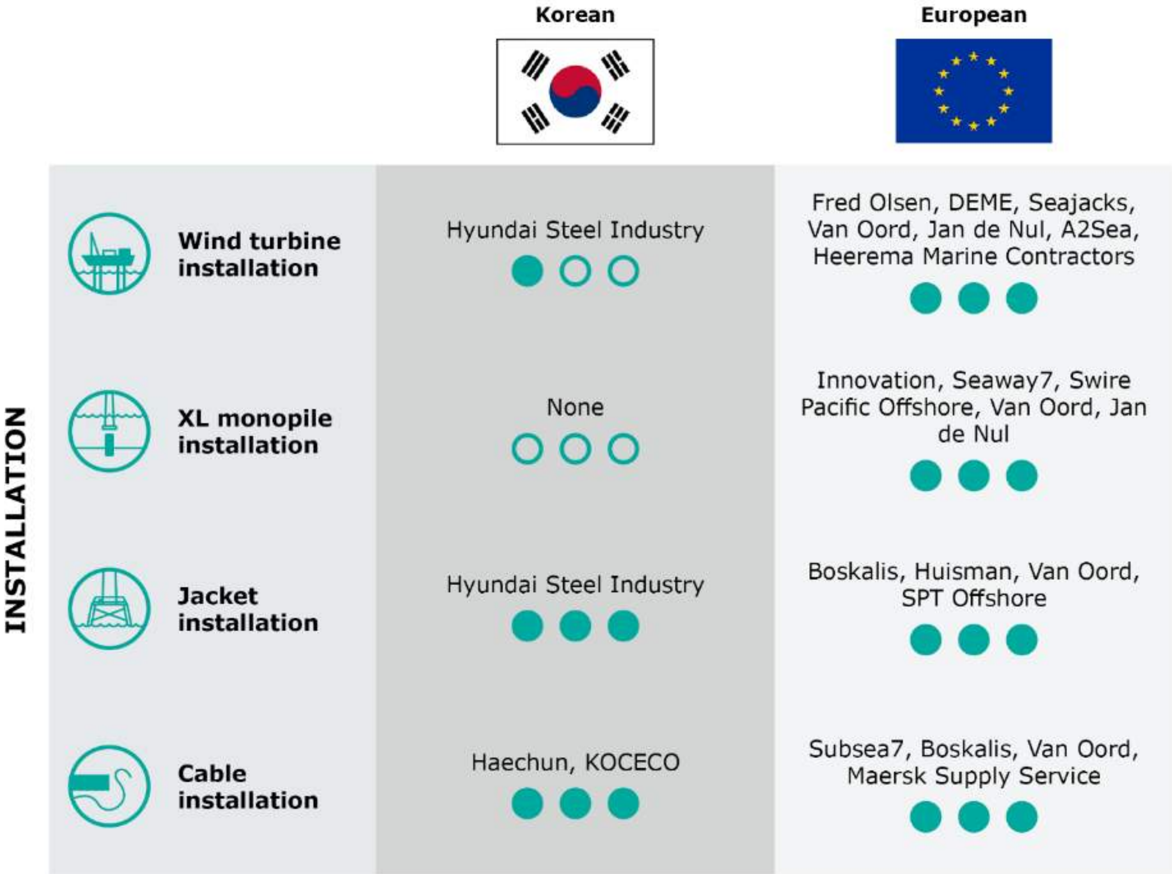


Figure 3-7 Selected major suppliers for installation in the Korean offshore wind market

Partnership potential

All Korean and European suppliers mentioned in Section 3.1.1 to 3.1.5 and Figure 3-5 - Figure 3-7 are representative companies in offshore wind or its relevant industries, and they all have their own features.

Project Developers

European developers have been pioneers of this industry since the early days of the offshore wind industry, and still occupy leading positions in the market to this day. Experiences and knowledge accumulated through many projects are key to minimize risks and unexpected additional costs during project implementation. On the other hand, Korean developers have the advantages of having rich understandings and experiences in Korean legislative and environmental circumstances. The Korean legislative framework and permitting processes are different to those in Europe (different organizational structure and scattered legislative framework) and environmental conditions are also somewhat different to those of the North Sea (different seabed strata and hydraulic conditions). Although the costs of project development are only a small percentage of lifetime project costs, the project developer has a disproportionately large impact on the success of the wind farm. Many of these companies also build and operate the wind farms they develop, which enables them to have a comprehensive feedback loop and optimize all activities holistically. The Danish developer Ørsted, for example, owned 17% of Europe’s total installed capacity at the end of 2020 [8]. By 2022, Ørsted will be operating almost 10GW in six countries [106].

The value of domestic-foreign partnerships lies in three key areas:

- Risk reduction and sharing
- Fast-tracking supply and installation
- Transfer of best-in-class knowledge

An extensive risk management system is critical for large wind farms, whose CAPEX costs are often in the low billions of Euros. Consequently, the value of associated claims can run into the hundreds of millions, as seen in some European projects. European developers have learned from these experiences and developed early detection systems and quality control measures to guard against globally applicable risks like:

- Contractual scope gaps
- Unexpected ground conditions
- A large variety of construction delays
- Bottlenecks in sourcing both equipment and labor
- Supplier inexperience or underperformance
- Weather downtime during installation

In a partnership scenario, the development and ownership of the wind farm would be shared, so that all remaining risk is also shared between the parties. Korean developers can reduce risk by applying their local connections, cultural understanding and knowledge of legal systems.

World-class offshore wind developers work to actively shape the market, enabling them to fast-track the expansion of supply chains in emerging markets and increase installation speed. They

- Conduct pro-active supply chain assessment to identify shortages or weaknesses
- Approach and develop suppliers to identify key improvement areas
- Follow up with suppliers using internal resources
- Contract supplier after requirements have been met

Ørsted, for example, followed this approach with Samkang, which delivered jacket foundations for its Ørsted's Changhua wind farm in Taiwan [107].

From their experience, European developers can also promote the formation of joint ventures between suppliers in order to strengthen weak links of the supply chain.

Korean developers can profit from leveraging these proven methods to build a supply chain in emerging markets and using their local knowledge to apply them.

Finally, European developers have a history of investing in knowledge transfer to other markets because they see it as key to the success of their wind farms.

This knowledge transfer applies to the development of suppliers, where continuous feedback and improvement loops are frequently used. It also applies to human resources working with the wind farms. On the developer side, it is common for staff working on a wind farm together to engage in training trips, secondments and workshops to ensure that knowledge is shared to all participants. In emerging markets where there is a lack of qualified labor, European developers have invested in initiatives to ease this shortage. Copenhagen Infrastructure Partners, for example, has teamed up with Taiwan's Chienkuo Technology University on an apprentice program to train future offshore wind maintenance technicians [108]. Ørsted is also looking ahead to the operation of its Taiwanese Changhua wind farm and is training Taiwanese technicians at its Danish wind farms for extended stays of 8 months [109].

For Korean developers, this knowledge transfer would be a chance to gain first-hand knowledge of methods from industry leaders, which could also be applied to other markets. After successful joint project developments in Korea, project development partners may even enter into broader collaborations in other countries.

Turbine

With regard to wind turbine manufacturing, the collaboration between European OEMs and Korean components suppliers can be expected. As explained in Section 3.1.2, a number of Korean companies are capable of manufacturing certain wind turbine components and supplying to European and Korean OEMs. It is possible to consider a plan for European OEMs to use these Korean components to satisfy local content expectations in Korea.

Partnerships directly between OEMs are also possible, if less common. Another partnership approach is for foreign OEMs to partner with industry partners with experience in a sector relevant to offshore wind, such as heavy industries, electricity, renewable energy or even main component suppliers.

Just this month, GE has taken this approach in Japan, where a strategic agreement between GE and Toshiba has been signed. According to the deal, the nacelles of GE's Haliade X turbine will be assembled, warehoused and transported in Japan by Toshiba. GE contributes the turbine technology and components for assembly [110].

Generally, in these types of arrangements, the domestic partner can contribute:

- Capabilities in local manufacture, assembly, warehousing and transportation
- Local qualified workforce
- Experience in domestic wind energy, offshore on onshore
- In-depth knowledge of domestic regulatory and legal aspects
- Good relationships to key domestic stakeholders
- Business development expertise and connections in the domestic market

While the foreign partner can contribute:

- World-class turbine technology
- Good connections to a mature supply chain, where foreign sourcing is required or advantageous
- Training and qualifying local labor, in case capacity is not adequate

In preparation for and during the operation and maintenance of the wind farm, the foreign OEM can provide hands-on training on its wind turbines outside of Korea.

Strategically, these collaborations may also use as a springboard for future joint development of wind turbine models specific to the Asia-Pacific region.

BOP

Thanks to solid fundamentals of the Korean supply chain and rich experiences of relevant industries, Korea is expected to supply most BOP components except XL monopiles within the short-term. XL monopile capabilities will need to be developed to meet the demand in the mid-term. To do so, Korean companies may be able to partner with foreign producers or manufacturers of fabrication equipment.

Floating foundations are an especially interesting technology for Korea because there is not yet a mature supply chain in other regions of the globe. The most common foundation type, semi-submersible, also plays to Korea's strengths in steelwork. This potential combined with the recent announcement by the government of Korea that a 6 GW floating wind farm will be developed in Ulsan by 2030 puts Korea in an excellent position to become a global leader in floating foundations [111]. Korean and European companies are jointly developing floating wind technology, and it is expected to supply and import this technology into the market around mid-2020s.

Partnerships are expected to be especially beneficial in installation, which must increase dramatically in speed (see section 3.2) for Korea to be successful in its goals. Korean contractors are well aware of the legislative and natural conditions of Korean waters and have a lot of experiences in site-specific conditions. European contractors have a variety of special installation vessels for offshore wind and have significant track records. A number of Korean companies are currently in the process of building specialized offshore wind installation vessels. Stakeholder engagement has indicated that the installation speeds now being seen in Europe are due certainly to the specialized vessel now available, but also in large part to the crews who have optimized the process over thousands of turbines. Transfer of this knowledge can be achieved by partnerships between installation companies. This collaboration may take the form of making use of each other's ships and crews or conducting training exercises together.

3.2 Short-term outlook for Korean supply chain

Although the development of Tamra Offshore Wind and Southwest Sea Offshore Wind demonstrate that the Korean supply chain is capable of developing, constructing and operating offshore wind farms, these two projects also demonstrated that the current supply chain is not mature and that improvements are needed to lower installation times, risks and development costs in order to achieve the 12 GW target.

One of the improvements required is to significantly reduce the total installation time of offshore wind farms. Table 3-1 summarizes the data of Tamra and Southwest Sea offshore wind farms.

Table 3-1 Project overview of Tamra Offshore Wind and Southwest Sea Offshore Wind demonstration site [112, 113]

	Tamra Offshore Wind	**Southwest Sea Offshore Wind demonstration site**
No. of WT	10	20
WF capacity (MW)	30	60
Type of foundation	Jacket	19 Jacket, 1 Suction bucket
Water depth at site (m)	16-20 m	8-15 m
Annual mean wind speed at 80 m	7.6 m/s	6.9 m/s
Distance to shore (km)	10 km	0.5-1.2 km
Date of project financing	March 2016	October 2018
First operation date	September 2019	November 2019
Soil condition	Weathered rock	Silty sand or sandy silt
Construction time	30 months	31 months
Construction rate	1 MW/month	2 MW/month
Project cost, EUR	123 million	374 million
Project cost, EUR/MW installed capacity	4.87 million	7.42 million

Table 3-1 shows that the construction time of the Tamra and Southwest Sea projects that were realized by a full Korean supply chain was 30-31 months. This equates to a rate of 1 MW installed per month at Tamra and 2 MW per month at Southwest Sea. This is significantly longer than the expected construction duration of comparable European offshore wind projects. The Netherlands' Borssele 1&2 offshore wind farm, for example, finished construction of 94 units of SGRE's SG 8.0-167DD model in only eight months, giving an installation rate of 94 MW/month [8]. Full details of the supply chain for the Southwest Sea Offshore Wind demonstration site are given in Appendix B.

With regard to the installation of the wind farms, the Korean supply chain has a high potential to develop rapidly, but whether this potential is realized will depend to a large degree on the number of projects built in the short-term, from which installation companies can gain further experience. Stakeholder engagement indicates that the speed and efficiency of turbine installation teams correlates directly with the teams' practical experience on projects and that it has taken a long time to develop this level of efficiency in Europe.

The production capacity of Korean wind turbine manufacturers is also expected to be a barrier to the quick ramp up of a full Korean supply chain. Doosan recently announced that the current production capacity is around 30 units of the Doosan 5.5 MW wind turbine on an annual basis, which is equal to 165 MW annually [114]. To realize the production of 12 GW within the next 8 years, the production capacity would need to be increased by a factor of 10.

Another key challenge in the short-term will be the track record of the Korean supply chain. Although some Korean suppliers have extensive experience and even supply the global market (tower and cable manufacturers), most suppliers only have a limited track record on relatively small project sizes.

This is especially important for Korea's wind turbine manufacturers. Although both Doosan and Unison are working on larger scale wind turbines, Doosan is the only Korean offshore wind turbine OEM which currently has offshore wind farms operating, with a total track record of 90 MW, all with their 3 MW turbine platform. Due to both, this short track record and a recent string of high-profile failures, the interests of both domestic and foreign developers in using Doosan turbines are still uncertain [115, 116]. High uncertainties dominate the overall impression of domestic wind turbine manufacturers, according to stakeholder engagement for this study. Stakeholder engagement also indicated that the price of domestic turbines is significantly higher than the price of foreign turbines, though the difference in price level could not be reliably determined.

The last important aspect of the short-term outlook is the impact of the wind turbine on project financing. Non-recourse project financing is a common method of financing wind farm projects. However, the lenders required projects be able to demonstrate their profitability and will not grant financing to projects that are seen as too risky. As the turbine is the heart of the wind farm, the turbine technology and contractual risk assessments carries great weight. These risk assessments are influenced by the design and guaranteed performance of the turbine but also by the track record of the wind turbine manufacturer. The combination of little track record and recent failures of domestic turbines mean that they are generally not regarded as bankable. The result is that projects using domestic turbines are unlikely to be granted project financing by foreign lenders. This cuts off access to a large source of funding, which could otherwise be used to accelerate the Korean offshore wind industry built-out.

The challenges discussed in here however, have been commonly seen in other countries, including Europe, at the early stages of offshore wind industry development. In fact, in global terms, Korea is in an excellent position compared to many other emerging offshore wind markets. Korea has strong capabilities in industries relevant to offshore wind industries: two of the global top twenty steel manufacturers are Korean companies and Korean shipbuilders play a leading role in the global industry. The experience in these industries can be put to good use for the offshore wind industry. Though improvements in efficiency and capacity are needed, stakeholder engagement has confirmed that Korea is already capable of delivering 50-60% of the offshore wind farm supply chain.

3.3 Mid-term outlook for Korean supply chain

Looking toward the mid-term, it is expected that the Korean capabilities regarding balance of plant will develop rapidly according to demand. However, if domestic demand is low or inconsistent, expansion of balance of plant capabilities will likely be slowed.

There may be some bottlenecks during the expansion, such as the availability of vessels. This constraint has been seen in European projects where vessels are critical for offshore wind turbine installation execution in Europe. As Europe is an attractive market for vessel operators due to its clear market visibility and project pipelines, Korea may not be able to reduce this bottleneck by using global vessel resources. There is only one vessel for the installation of domestic offshore wind projects and few orders announced for new installation vessels in Korea, which may cause delays in the installation.

The production capacity and timing of large diameter (XL) monopiles is also uncertain, as these have yet to be developed in Korea but are expected within the mid-term according to stakeholder engagement.

On the installation side, an improvement in installation time is necessary, but is expected to be achieved by gaining additional experience. A very simplified calculation assuming 1) an installation time of 18 months for a windfarm of 500 MW and 2) that three windfarms are constructed simultaneously, shows that it will take 12 years to install 12 GW of offshore. This is in line with the installed capacity in Europe between 2006 and 2016, which can be considered as the ramp-up years of the European offshore wind industry. To install 12 GW in the next 8 years, an average installation rate of 125 MW/month is required. This could be achieved, for example, if three wind farms of 500 MW were built every 12 months, giving an average installation rate of 41.6 MW/month for each individual wind farm and 125 MW/month nationally. These indicative numbers show that an increase in installation speed per wind farm by a factor of at least 20 is needed for Korea to fulfill its goal. This rate and faster is well within the reach of wind farms being constructed today in Europe.

The small average project size is also of some concern. Many small projects may spur excessive competition for the resources of the domestic supply chain, causing project delays and higher prices. In addition, some domestic suppliers, such as those of installation vessels, will need to make large capital investments to serve growing demand. However, companies may not be willing to take the investment risk if the small project size means that their return on investment is less certain or takes longer and would rather invest on larger projects.

In the mid-term, the wind turbine is expected to remain the weakest link of the domestic supply chain. Larger models which are currently under development by domestic OEMs will contribute towards closing the competitive gap between foreign and domestic turbines. However, the issue of track record and project developer confidence in the product will remain until domestic OEMs can install the newer models and demonstrate good performance.

3.4 Supply chain scenarios

A natural option to decrease costs and risk for offshore wind is to utilize the strong and mature part of the domestic supply chain and to supplement the weaker parts by using established global supply chains.

In order to analyze the impact of supply chain concepts, this study defines two supply chain scenarios which are used as a basis for further analysis.

The Korean market has currently been focusing on driving the industry based on a domestic supply chain. This approach is described in Table 3-2 as "Domestic Scenario".

To mitigate the higher risks and uncertainties associated with the domestic scenario, Korean companies may also choose to enter into partnerships.

Partnerships can be represented within a wind farm in many areas and forms. Considering the solid fundamentals of relevant industries in Korea (discussed in Section 3.3) and assuming adequate expansion of domestic capacity, it is estimated that all BOP (except XL monopiles) installation, commissioning and O&M are supplied by Korean companies for a bottom-fixed wind farm in the mid-term. In this case, the XL monopiles and the wind turbines would be supplied through foreign partnerships. For a floating wind farm, semi-submersible floating foundations are expected to be produced domestically. These cases are illustrated in Table 3-2 as the "Partnership Scenario".

These scenarios are not intended to represent a prediction of the development of the domestic supply chain or to represent a specific chronology for supply chain expansion. Rather, they are meant as tools to support the impact analysis of this study.

Table 3-2 Breakdown of supply chain scenarios from 2026 (F indicates foreign supply; D indicates domestic)

Category		Category split	Partnership Scenario	Domestic Scenario
Project development		DEVEX scaled on wind farm size, based on market maturity level	D	D
Turbine supply and installation		Supply Installation	F	D
Foundation supply	Bottom-fixed	Monopile and transition piece supply Jacket and pile supply	F	D
	Floating	Floater supply Onshore assembly Mooring supply	D	D
Foundation installation	Bottom-fixed	Monopile installation Transition piece installation	D	D
	Floating	Mooring installation Floater installation (towing by tugboats)	D	D
Array cable supply and installation		Array cable supply Array cable installation	D	D
Transmission & grid		Transmission (Onshore and offshore substations, export cables) Grid costs SCADA	D	D
Operation & Maintenance		Operation and maintenance cost Owner’s cost, Logistics cost, Operations cost	D	D
Other		Travel, Resource costs Operation preparation Construction management Insurance	D	D

For the sake of simplicity, each category in Table 3-2 is marked as either foreign (F) or domestic (D) supply. We note, however, that the globalized nature of supply chains used by many companies significantly blurs this simple dichotomy. It is common for major parts of the wind farm, even if they are manufactured by a “domestic” or “foreign” supplier, to contain parts supplied It is common for major parts of the wind farm, even if they are manufactured by a “domestic” or “foreign” supplier, to contain parts supplied both domestically and from outside the country. However, for the purposes of this study, it is necessary to simplify the origin of supply in this way.

On the basis of these scenarios, detailed quantitative analyses in terms of cost of energy, economics, and job creation are performed, and the results are described in Chapter 4 and Chapter 5.

3.5 Summary

In global terms, Korea is in an excellent starting position compared to other emerging offshore wind markets. Korea has strong capabilities in steel and shipbuilding industries, which are relevant for offshore wind. The Tamra and Southwest Sea offshore wind farms were executed by a 100% domestic Korean supply chain, but these projects also revealed the need for significant improvement, especially in installation times.

Assuming an adequate and consistent demand, the Korean BOP supply chain has a high potential to expand rapidly in the coming years.

In the mid-term, the wind turbine is expected to remain the weakest link of the Korean supply chain. Domestic OEMs Doosan and Unison have announced significantly larger turbine models than those currently on the market – 8 MW and 10 MW respectively. These new models are expected to be more competitive than the comparatively small offshore turbines currently available. However, these new turbines will need to first establish a track record to build industry confidence before they are expected to be widely used.

Bottlenecks of installation vessel availability could be another weak link of the Korean supply chain. As Europe is a more attractive market for vessel operators because of their clear pipelines, Korea may experience difficulties in resolving these bottlenecks.

To achieve the target of 12 GW offshore wind in 2030, active stimulation of the offshore wind industry is needed, which cannot be achieved by the Korean government only. Despite solid fundamentals of Korean industries relevant to offshore wind, Korea still has lacking track records, and industries need to adapt to this multi-disciplinary industry, which is expected to take more than 5 years. It may be possible to meet the goals with the involvement of foreign supply chain and some swift and active government support. Trying to meet the goals with a 100% domestic supply chain will cause a high risk of missing the targets.

The main points for improvements of the Korean supply chain investigated in this study are:

- Limited track record in offshore wind turbines
- Low capacity for turbine manufacturing
- Installation vessel bottlenecks
- More speed and efficiency in installation

The European supply chain has gained extensive experience in the development, engineering, installation and operation of offshore wind. Especially in the field of the installation of wind farms, but also in the field of designing and supplying wind turbines and the associated foundations, European parties can contribute relevant knowledge and experience to the Korean supply chain.

By using the lessons learned from Europe in the field of policy, creating an attractive investment climate and free market economics, offshore wind farms can be developed within shorter periods and with decreased risk. This will result in lower costs and accelerate the achievement of the set targets with regards of offshore wind.

A faster developing Korean supply chain offers sustainable employment opportunities for the future. By focusing on the accelerated development of the Korean supply chain in collaboration with a globally available supply chain, the opportunities for Korea to build out the export capacity into the nearby markets and to become one of the market leaders in offshore wind in Asia will increase.

LEVELIZED COST OF ENERGY

4 Levelized Cost of Energy

Levelized cost of energy (LCOE) refers to the average price of electricity required to cover the lifecycle cost of a project. Industry and policymakers commonly use LCOE as a measure to compare different generating technologies and support policy decisions on future energy sources. Using LCOE, this report provides a qualitative assessment of the Korean government's offshore wind power promotion roadmap regions and sheds light on potential areas for further development towards realizing the 12 GW target by 2030.

4.1 LCOE analysis of selected promotion regions

Based on the "OSW collaboration plan" published in July 2020, Korea will prioritize development of offshore wind farms in the five highlighted regions below with green and light blue; Incheon, South Jeolla, North Jeolla, Ulsan and Jeju Islands [117].

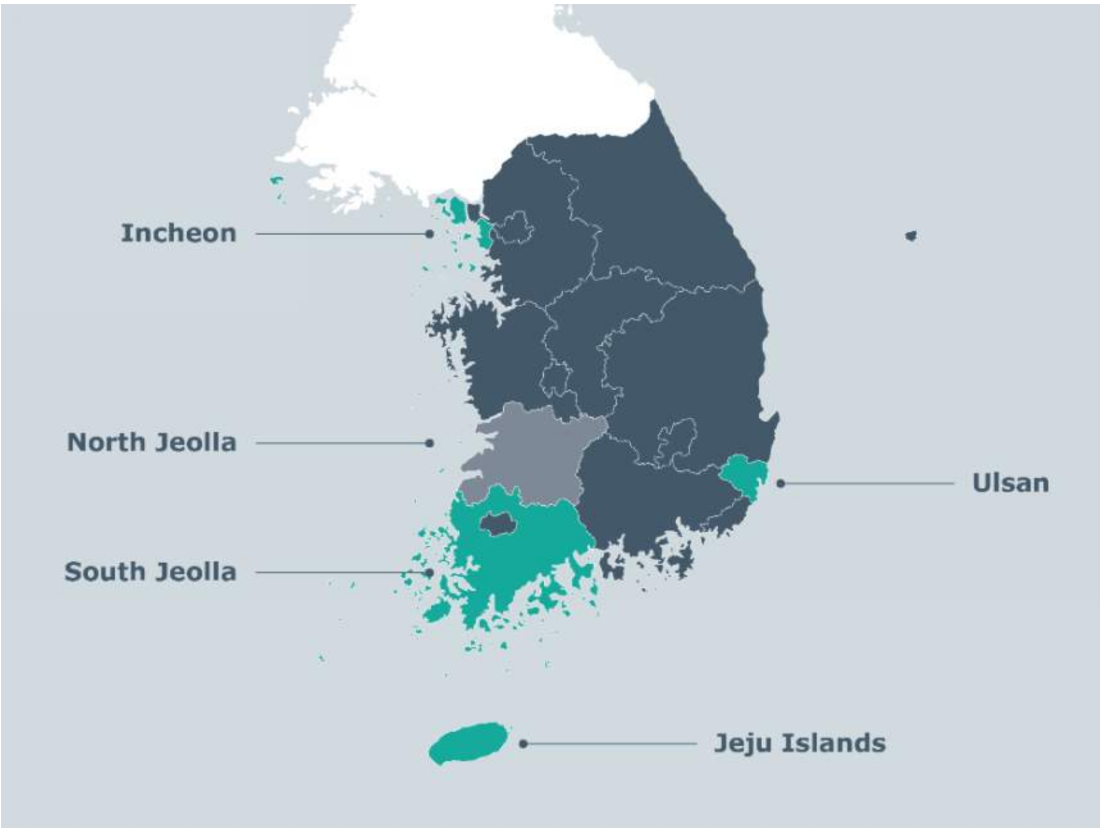


Figure 4-1: Promotion areas for offshore wind development, highlighting with green the selected regions for this study

This study focuses on the regions having most traction both from foreign and domestic developers for the upcoming build-out: Incheon, South Joella, Ulsan and Jeju Islands (highlighted in green in Figure 4-1).

4.1.1 Definition of reference cases

The cost model employed for the study is provided by Aegir Insights and is a proprietary techno-economic offshore wind performance model which has been developed by the company in cooperation with industry and academic partners.

The cost divisions used for this study are based on the scope of the activities and contracts according to common industry practice. These cover the main wind farm components such as turbines, foundations, array cables and substations split on supply and installation contracts. The cost structure applied for the LCOE assessments is based on total project cost split and detailed in Appendix C.

When assessing the commercial attractiveness and economic viability of an offshore wind market, reference sites are developed to indicate how a generic offshore wind project would perform in a given area. These sites are chosen to represent typical conditions in the area. Reference sites are well suited to compare LCOE levels between different regions and across energy sources, both domestically as well as internationally.

After the location of the reference sites is chosen, calculation parameters are adjusted to reflect that site as accurately as possible. The reference cases are adjusted to the local site characteristics driving the value of the wind project. Wind speed, water depth, distance to ports and the transmission grid are the main drivers of value differences when applying the technology assumptions to different offshore locations.

Finally, local market conditions are reflected. Availability of competitive domestic supply chain may allow saving in transportation costs, but immature supply chain on the other hand may result in higher risk premium for contracts impacting total project contingency. Local regulatory aspects are also adjusted for. Permitting processes impact the speed at which the project can be approved and hence the project development cost.

Publicly available data on other key value drivers such as wind resources, water depth, ports and transmission stations are then applied to the model to simulate the construction schedule, total project cost and power generation for the lifetime of the wind farm. Together, these form the basis for the reference case LCOE.

Time horizon for commercial wind farms in Korea

The public waters occupancy permit for installing a wind measurement LiDAR gives exclusivity to an area that is within a five km radius of each meteorological measurement device. A minimum commercial scale project capacity is assumed to be 500 MW for mid-2020 deployment for an exclusivity area.

Taking the wind farm size into account, the deployment year for a commercial size offshore wind project of 500 MW is assumed to be five years from first permit (public waters occupancy permit) to COD assuming no major delays arriving at COD in 2026. Minimum 1 year of meteorological data collection from the LiDAR is required whereafter an Electricity Business License can be secured, triggering a preparation period effectively starts lasting maximum 4 years; during this time, the applicant needs to reach COD or get permission to extend period. This gives a permitting timeline of minimum 5 years assuming no delays.

Turbine assumptions

The selection of the wind turbine generator is one of the key considerations when developing a wind farm. Factors like manufacturer experience and product reliability, production volume, cost factors, availability factors, and maintenance contracts have been identified as primary contributing considerations by developers [118].

An equally important turbine selection criteria is the turbine configuration, i.e. the generator capacity rating and rotor size. Manufacturers commonly use the International Electrotechnical Commission (IEC) system to specify at what wind conditions their turbines are suitable for. The IEC classification system ranges from high wind to low wind regime, depending on several parameters. For the purposes of this study, the average annual wind speed (m/s) and generic class specific capacity (W/m^2) are the most relevant:

- Class 1 (high wind): 10 m/s, ≈ 350 W/m^2
- Class 2 (medium wind): 8.5m/s, ≈ 275 W/m^2
- Class 3 (low wind): 7.5 m/s, ≈ 237 W/m^2
- Class S: values specified freely by the designer

Class 1 turbines are built and optimized for high wind regimes and show the highest rotor matched with the highest generator available in the market, to achieve the highest output. Class 3 turbines have been built and optimized for low wind speed areas. As a result, class 3 turbines have larger rotors relative to their generator size than class 1. This relationship between rotors and generators is expressed by the turbine's specific capacity, which commonly differs between the IEC classes.

The specific capacity is expressed in watts per square meter of rotor swept area, abbreviated W/m2. This unit conveys the amount of energy a wind turbine intercepts from the wind relative to its generator capacity. The immense amount of wind intercepted by the class 3 turbine is illustrated in Figure 4-2.

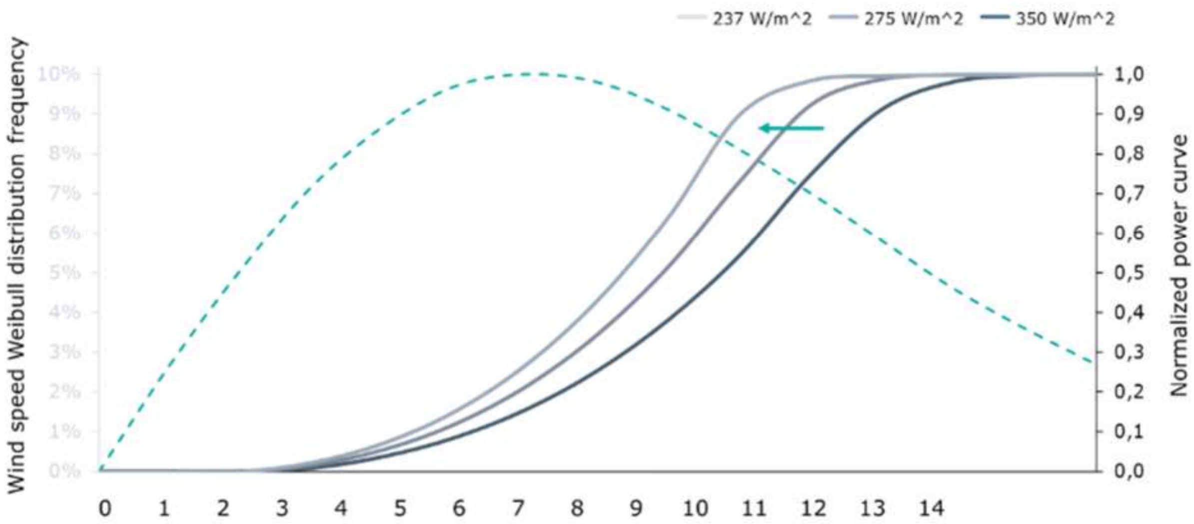


Figure 4-2: Correlation between turbine specific capacity and power curve performance under a low wind regime with a mean annual speed of 7.3 m/s and a shape factor (Weibull k value) of 2

Figure 4-2 shows the wind speed distribution at the Incheon reference site. As the specific capacity decreases, the power curve's inclining angle increases, resulting in a shift of the power curve to the left and higher use of the annual wind speed distribution resulting in higher capacity factor.

European offshore wind turbine manufacturers, such as Vestas, Siemens Gamesa Renewable Energy, and General Electric, have commonly operated in the North European seas with high wind speeds and therefore based their top turbine platforms on large rotors and generators. Global manufacturer leader Vestas have recently announced a 15 MW turbine with a huge rotor of 236 meters, for deployment in 2025. However, as low wind speeds characterize the wind regime of Korea, global OEMs will likely offer their largest turbine platform for deployment in 2026 in a downscaled generator version. This means that foreign manufacturers would maintain the large rotor but lower the generator rating to decrease the turbine's specific capacity and adapt the power curve to the low wind regime, as mentioned in the beginning of this section. This has been confirmed by industry engagement in relation to this study.

Korean turbine manufacturers are currently pursuing the development of a tailored low wind turbine for the Korean and Asian market. Korean wind turbine manufacturer Doosan has announced an 8 MW turbine for deployment in 2022. This turbine is designed to maintain a capacity of at least 30% even at a low wind speed of 6.5 m/s by using a large rotor diameter of 205m. Another Korean manufacturer, Unison, announced a 10 MW wind turbine with a reported commercialization target in the mid-2020s. Of the announced domestic turbines, stakeholder engagement has indicated that the Doosan 8 MW turbine is currently the most likely turbine to see commercial use in the mid-2020s.

Table 4-1 shows an overview of selected public announcement of turbines available to the Korean market in the mid-twenties, based on platforms offed by the manufacturers.

Table 4-1: Public announcement of key turbines expected to be available to the Korean market in the mid-twenties.

	Foreign			**Domestic**		
Manufacturer	Vestas	SGRE	GE	Doosan	Doosan	Unison
Model name	V15-236	SG 14-222	Haliade-X 14 MW	WinDS5500	DS205-8 MW	Hemu X
Rating (MW)	15	14	14	5.56	8	10
Rotor diameter (m)	236	222	220	140	205	209
Specific capacity (W/m^2)	343	361	368	361	242	291
Commercially available (OEM estimate)	2025 [119]	2024 [120]	2025 [121]	2019 [122]	2022 [122]	2026 [123]

Returning to the two supply chain scenarios defined in Section 3, the partnership scenario is assumed to use a representative foreign turbine with a 230-meter rotor that has been adapted to the low wind regime by downscaling its generator to correspond with a turbine specific capacity of 237W/m^2.

For the domestic scenario a representative domestic turbine with a rotor of 207 meters and same turbine specific capacity of 237W/m^2 has been chosen. The corresponding baseline assumptions for the turbine size for the domestic and foreign suppliers are shown in Figure 4-3**.**

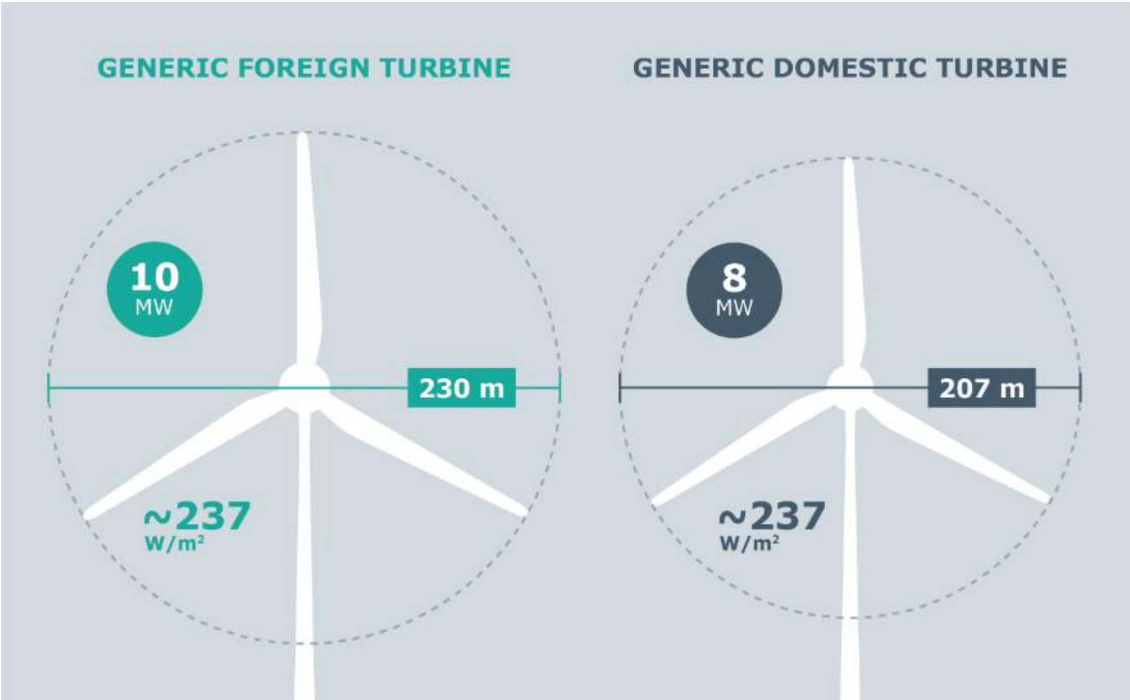


Figure 4-3 Generic domestic and foreign turbine configurations

In addition to the size difference of the two turbines used in the scenarios, this study also applies some further modifications to the generic domestic turbines which attempts to reflect the amount of experience and a global foreign manufacturing would have over a smaller domestic one. Wind turbines are complicated electromechanical systems and with many dynamically interfacing components. Therefore, generally speaking, there is a steep learning curve for introducing a new turbine platform and usually it takes several years to optimize this platform and achieve a reliable performance. However, a large amount of experience can be drawn from existing, older, well proven, and tested platforms. As European manufacturers have decades of experience developing new turbine platforms and benefits from the huge market it is serving compared to a Korean domestic manufacturer with lower track-record, this study assumes that a foreign turbine would have higher reliability and lower downtime. To reflect this difference in experience, some model parameters have been adjusted for the generic domestic turbine. The parameters are based on a combination of expert experience, stakeholder engagement and literature review. Due to a lack of data on the price of domestic turbines, this study does not consider any price difference between the foreign turbine and domestic turbine. The parameters and values are shown in Table 4-2.

Table 4-2 Selected parameter modifications for a domestic scenario

Key parameter	Assumption (all % in absolute terms)
Lifetime	5-year reduction
Long-term availability	2% reduction
Turbine contingency	5% increase
OPEX	10% increase
Ramp up availability	5% decrease in the first 3 years
Total project contingency	2% increase

Foundation assumptions

Since the early years of the offshore wind industry, monopiles have been the predominant technology used for fixed-bottom foundations [124]. The challenge of the monopiles was that the attractive sites with shallow waters of less than 30 m water depth were quickly exploited. It was thought that the jacket structure foundation would take over as water depths increased.

But due to the extensive use of monopiles this technology developed faster than expected. Through years of incremental design and manufacturing optimizations, the monopiles have reached a point where they are in many cases the preferred foundation option in waters up to around 60 meter depth. This has left only a small market for the jacket foundation [8]. Today it is expected that floating foundations will be a widely used solution at water depths above 60 meters. This leaves only monopiles and floating foundations to be used in the reference cases for this analysis.

This study assumes a generic semi-submersible floating substructure, as this substructure type is currently the most commonly planned and constructed type on floating projects globally compared to the other dominant concepts, tension leg platform and spar.

Semi-submersible concepts depend primarily on buoyancy and water plane area to maintain static stability, and as such, most concepts have a systemic advantage of being stable enough to be towed out from assembly location to site with the wind turbine already installed, before connecting the mooring lines. Semi-submersible substructures also have relatively shallow draft requirements compared to spar concepts, allowing more port flexibility for assembly at quayside, and then be towed to its offshore operating site with a limited amount of activity to be carried out at sea. It is generally assumed that conventional semisubmersible platforms can be deployed in depths ranging from 50 m up to beyond 1000 m water depth [125]. Semi-submersibles generally have flexibility on mooring solutions, having compatibility with conventional catenary mooring arrangements, and also possibility for next generation semi-taut moorings or other novel concepts.

As of 2019, more than 90% of proposed floating projects globally are using semi-submersibles. Also, further floating concepts mature, optimum platform choice may be dependent on site-specific variables, such as bathymetry, soil conditions, availability of vessels and infrastructure and other factors [126]. The conventional semi-submersible concept is illustrated in Figure 4-4, below.

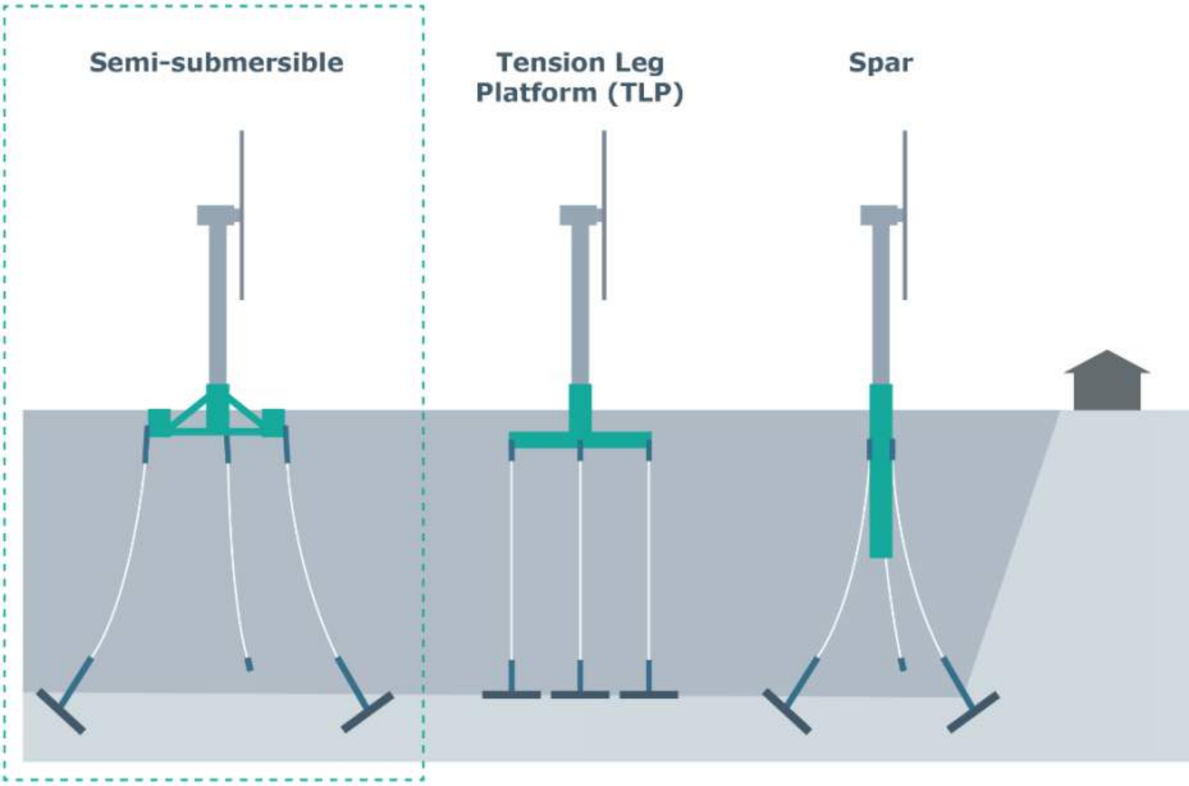


Figure 4-4: Overview of main floater concepts

Similar to the manufacture of wind turbines, monopile fabrication has shown a steep learning and optimization curve. A significant experience gap between a global manufacturer with a large portfolio and a domestic manufacturer with a small portfolio exist for the monopile foundations used in the study. Therefore, model parameters were adjusted in the domestic scenario to reflect this. The parameters and values are shown in Table 4-3.

Table 4-3: Selected monopile modifications to a domestic foundation

Key parameters	Assumption (all % in absolute terms)
Monopile fabrication cost	20% increase
Monopile & Transition piece contingency	20% increases

Overview of reference cases

The reference cases that have been adjusted to Korean conditions are summarized below in Table 4-4 and show the starting point for making the supply chain scenario assessments. The assumptions for turbines are divided into "F" for foreign supply and "D" for domestic supply, which reflect the generic turbines from Figure 4-3.

Table 4-4: Assumption overview of reference cases

		Incheon	South Jeolla	Jeju Island	Ulsan
					
Wind farm capacity (MW)		500	500	500	500
Turbine rating (MW)	F[1]	10	10	10	10
	D[2]	8	8	8	8
Turbine Rotor size (m)	F	230	230	230	230
	D	207	207	207	207
Turbine Lifetime (Years)	F	30	30	30	30
	D	25	25	25	25
Foundation type		Monopile	Monopile	Semi-submersible	Semi-submersible
Water depth at site (m)		25	55	105	140
Annual mean wind speed at 100m height (m/s)		7.25	8.25	7.25	8.00
Distance to grid (km)		50	75	15	70
Distance to construction port (nm)		55	65	40	40
Commercial operation date		2026	2026	2026	2026

1 Foreign supply; 2 Domestic supply

4.1.2 LCOE results

As presented in detail in Table 3-2, this study considers two supply chain scenarios. A percentage lifetime cost breakdown of categories for the reference cases is given in Appendix C.

By combining the scenarios above with the assumptions of the reference cases in Table 4-4, lifetime costs and annual energy production are modelled for each reference case and scenario. A discount rate of 7.5% for all scenarios have been applied in the analysis. The results are summarized in Appendix D.

Although Jeju and Ulsan's floating sites are closer to a construction port than the fixed-bottom sites Incheon and South Joella, it does not outweigh the higher cost associated with floating foundations. As a result, the floating sites have LCOE ranging between 98-120 EUR/MWh. In contrast, the lowest LCOE Levels are found at the fixed-bottom sites ranging between 75-95 EUR/MWh. These results are shown below in Figure 4-5. For all sites, the partnership scenario provides the lowest LCOE values due to the use of a mature foreign turbine and monopile supply chain.

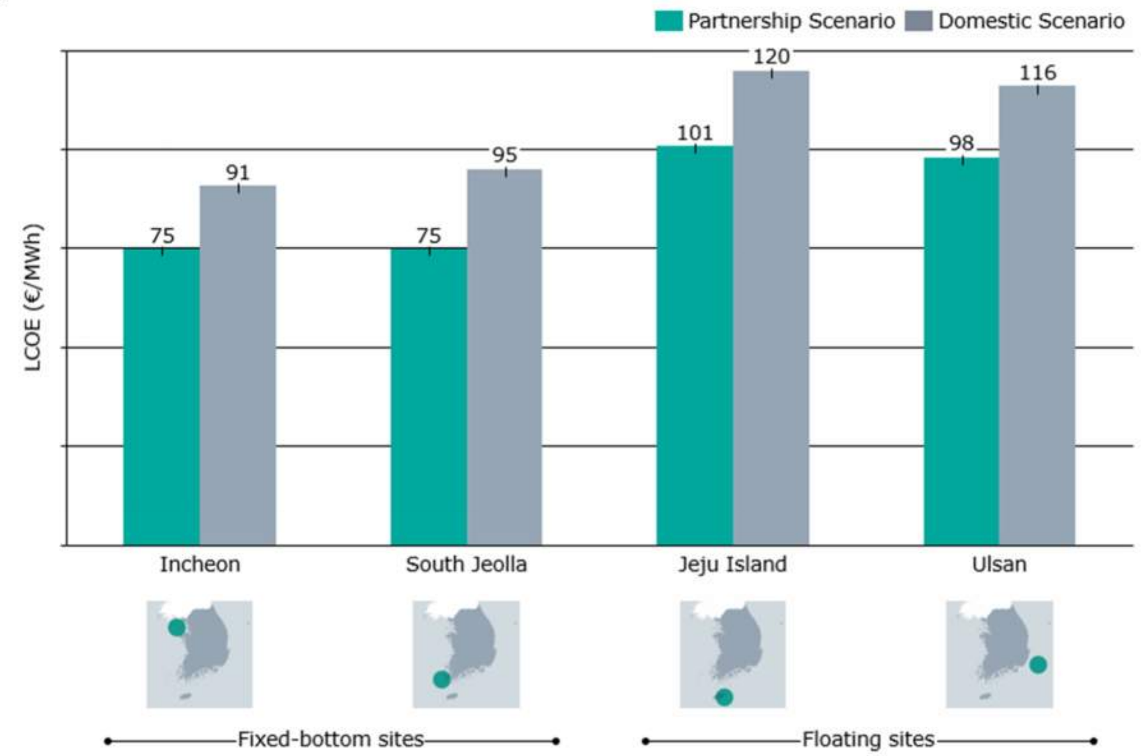


Figure 4-5: LCOE at reference sites in 2026 for all scenarios (EUR/MWh in 2021 prices)

Figure 4-6 shows a comparison of the farm capacity factors among all four locations. The capacity is directly correlated with the wind speed, therefore, South Joella, which has the best wind conditions, achieves the highest capacity factor in all scenarios, followed by Ulsan. As the foreign turbine platform benefit from years of experience, it has a more reliable performance compared to a less experienced turbine platform, hence the foreign turbine achieves higher availability and thus a higher capacity factor. Additionally, due to the lower generator size of the domestic turbine, a larger number of turbines is required in the wind farm which increases the wake loss resulting in lower production.

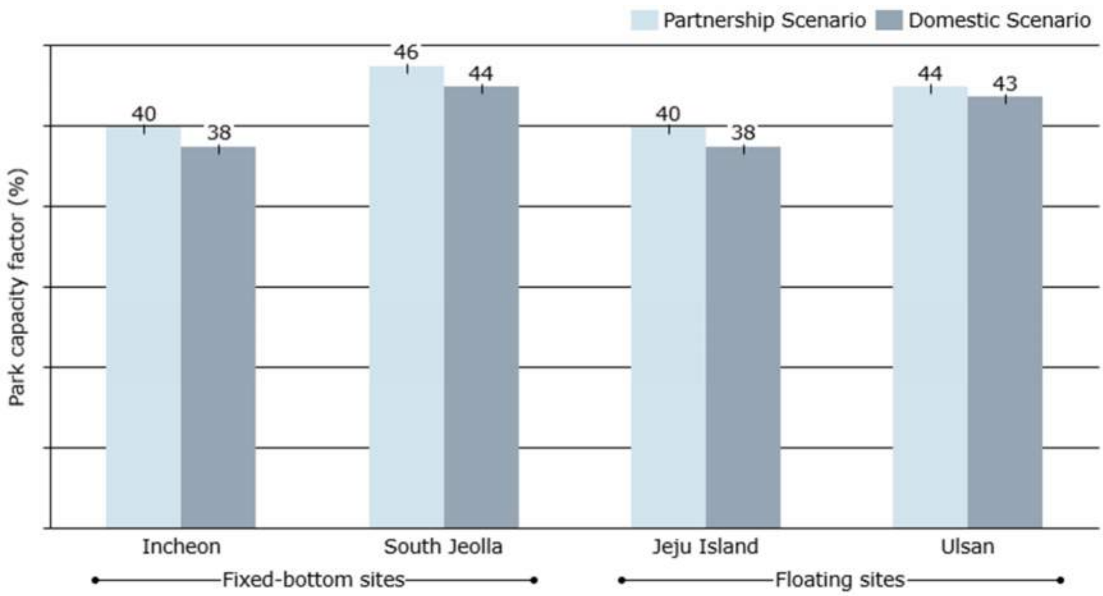


Figure 4-6: Capacity factor of reference sites for all scenarios

The capital expenses of the four locations are shown in Figure 4-7. Turbine and foundation supply and installation, and operation expenditures are the three main cost parts in a wind project. With this in mind, it is no surprise that Incheon scores lowest in CAPEX with its shallow waters and short distances to shore and port. High water depths are also the reason that Ulsan has the highest CAPEX.

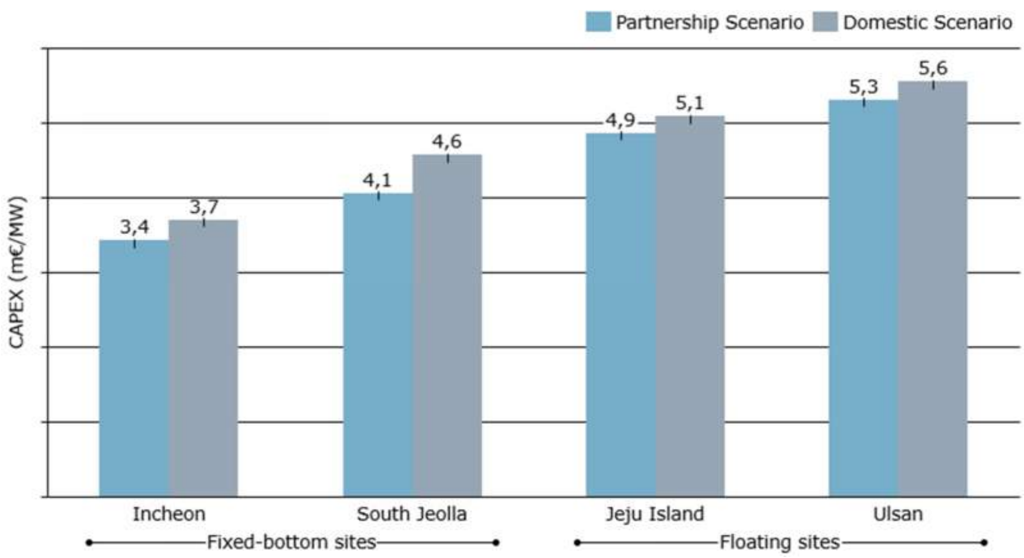


Figure 4-7: CAPEX of reference sites for all scenarios (EUR/MWh in 2021 prices)

Figure 4-8 depicts the operation expenditures among the four locations. As the floating wind technology is still at an early development stage and operation information is scarce, it has been assumed that the operation procedure is the same for floating and fixed-bottom sites as there are no evidence in literature of a cost difference for OPEX floating compared to OPEX bottom-fixed. Therefore, OPEX is mainly driven by turbine reliability and distance to O&M port.

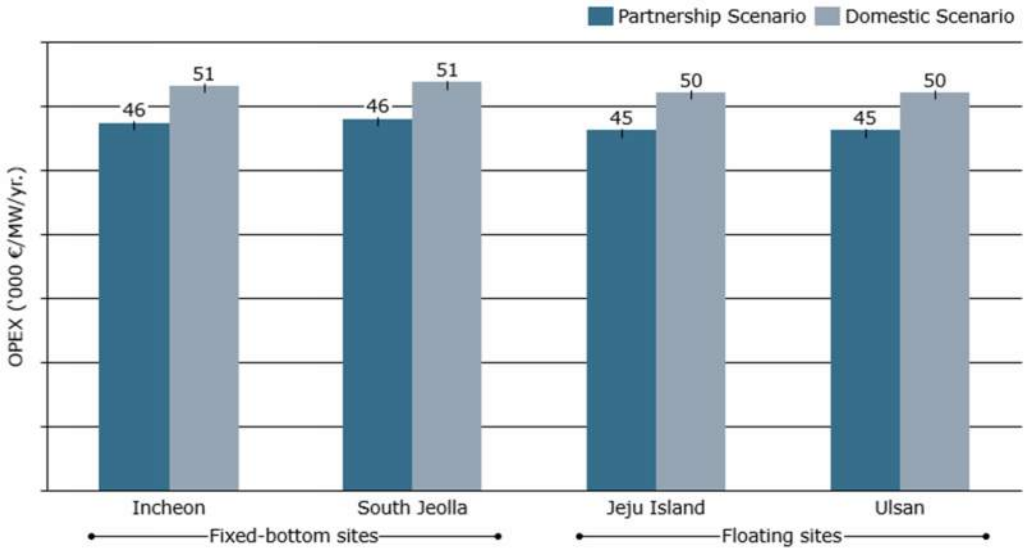


Figure 4-8 OPEX of reference sites for all scenarios (EUR/MWh in 2021 prices)

Bottom-fixed cumulative LCOE difference

The cumulative effect in LCOE between the partnership and domestic scenario is illustrated in Figure 4-9. A significant increase in LCOE across all subcategories can be seen between the two supply chain scenarios. The larger LCOE difference can be explained by the lower development stage turbine that is smaller in size compared to the more developed foreign turbine. As a result, a higher number of turbines is required, increasing the LCOE on all subcategories. Nearly a fourth of the increase arises from a lower wind farm capacity factor between the two scenarios. The lower wind farm capacity results from a lower turbine availability, a shorter lifetime, and higher wake losses induced by more turbines in the domestic scenario.

In a broader economic perspective, the difference between the LCOE levels amount to approximately 870 mil. €$_{2021}$ over the lifetime for a 500 MW size plant at Incheon. This value reflects an increase in the offtake price of 16.5 €/MWh multiplied by the lifetime production from the partnership scenario. It should be noted that this value cannot be extrapolated to other park size or years, as it would not consider the economics of scale or technical improvement, which might change the difference between the two supply chain scenarios.

Floating cumulative LCOE difference

The cumulative effect in LCOE between the partnership scenario and the domestic scenario is shown in Figure 4-10. The figure illustrates the change in the LCOE build-up as the foreign turbine in the partnership scenario is changed to a domestic turbine. As the domestic turbine is smaller, more turbines are required to reach the same wind farm size. Additionally, due to the performance and availability difference between the foreign and domestic turbine, lower energy production is reached. Consequently, an increase in prices for all subcategories are seen in Figure 4-10.

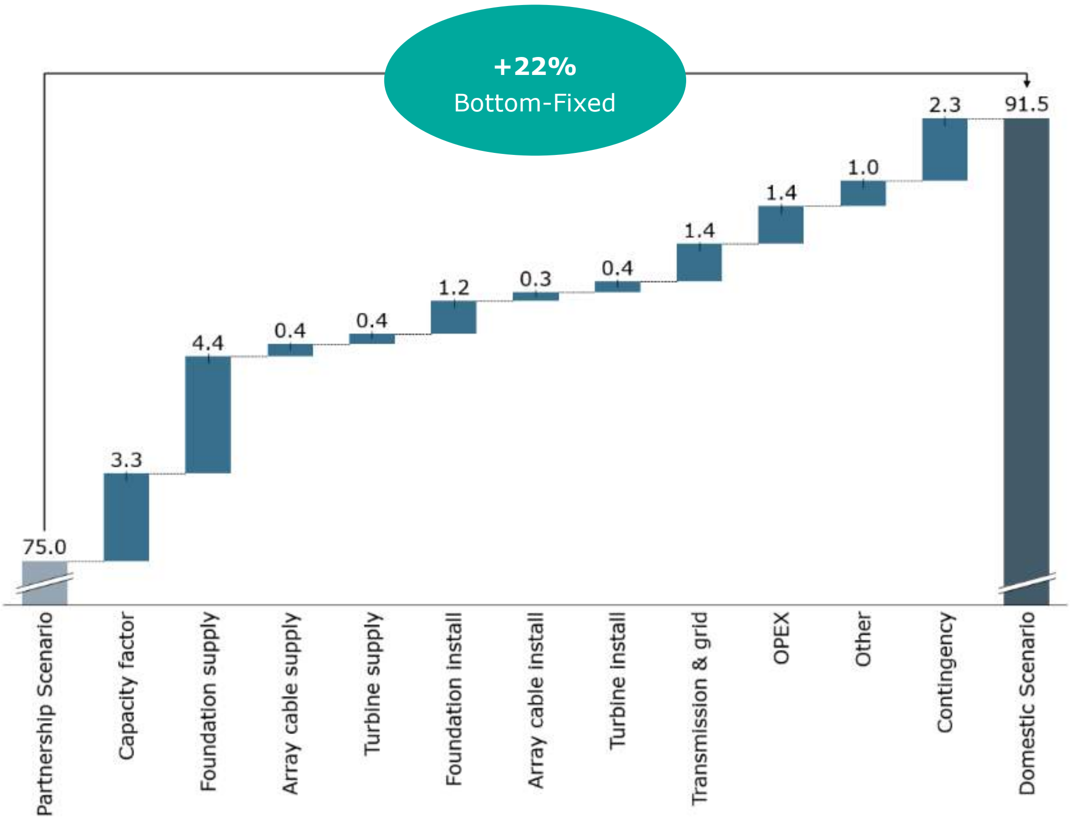


Figure 4-9 LCOE bridge for Incheon reference site from partnership scenario to domestic scenario (EUR/MWh in 2021 prices)

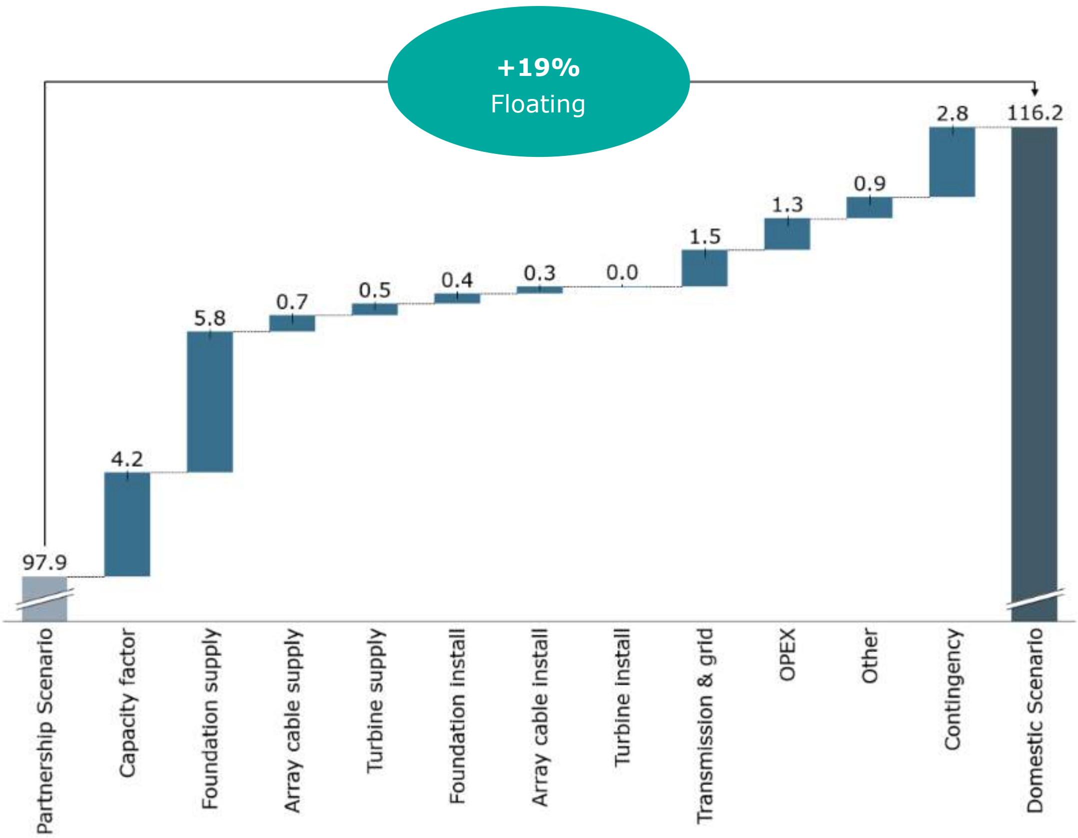


Figure 4-10: LCOE bridge for Ulsan reference site from partnership scenario to domestic scenario (EUR/MWh in 2021 prices)

4.2 Risks of domestic supply

While the European offshore wind supply chain has matured through the delivery of 1.5-3.5 GW annually since 2013, it has been able to minimize some key risks in the process [8]. Many of these risks relate to the turbine technology used. The primary mitigation method for turbine technology risks is for OEMs to establish a track record for turbine platforms and then to improve and continuously develop them over time. The longer the track record of a certain turbine platform, the less perceived technology risk.

The delivery risk of the foreign-supplied turbines used in this study is low, as even future developments are for the most part perceived as a continuation of current platforms, according to stakeholder engagement. On the other hand, stakeholder engagement has indicated that the delivery risk for domestic suppliers is perceived as high to prohibitively high. This is primarily due to the lack of offshore track record and to the large development steps currently undertaken by domestic suppliers. Doosan's largest turbine currently operating offshore is 3.3 MW and the company plans to make their 8 MW WTG available in 2022. An even larger technology jump is planned by Unison from a 4.3 MW onshore wind turbine to 10 MW offshore turbine by 2026.

Precisely due to this lack of track record, it is not possible to definitively quantify the risks associated with the use of domestic turbines. Therefore, the following analysis aims to illustrate the possible economic range of these risks with sensitivities and examples.

New turbine platform

When developing and launching a new turbine platform, there is a potential risk of delay in delivering and a threat for underperforming in terms of availability. If a developer commits to using domestic turbines and an 8 MW turbine is not available in the mid-2020s, the developer will have to rely on the second-best domestic option: a 5.56 MW offshore turbine with a rotor diameter of 140 m. This option would yield an LCOE of 131 €/MWh and a total lifetime energy production of 32,400 GWh compared to 91.5 €/MWh and 41,900 GWh for the 8 MW turbine configuration as seen in Table 4-5**.** Approximating the value of the potential financial increase through an LCOE approach, an estimated that 1.25 billion $€_{2021}$ is lost due to the increased LCOE of the second-best option for a park size of 500 MW. This value reflects an increase in the offtake price of 39 €/MWh multiplied by the second-best option's lifetime production.

Table 4-5: Value of delivery risk for Incheon reference site in 2026

	Turbine rating (MW)	Turbine rotor (m)	LCOE (€/MWh)	Lifetime production (GWh)
Domestic scenario	8	207	92	41,900
Second-best option	5.56	140	131	32,400
Difference	2.44	67	39	9500

4.3 LCOE heat mapping of Korean offshore wind

From a total market potential perspective value heat mapping is an impactful tool to map market diagnostics and screen a market for attractive sites to build-out offshore wind projects. For Korea the value heat map can highlight new potential areas for offshore wind deployment towards reaching the 12 GW target.

Value heat mapping is essentially a collection of thousands of individual LCOE calculations performed across an entire offshore wind market. Each calculation has a unique combination of wind speed, water depth, distances to port, shore, and transmission length, which are key drivers in determining LCOE. Factors not depending on the specific location are kept fixed. The reference cases used in the heatmap calculations are based on the partnership scenario.

For areas with a combination of low wind and deep water, a relatively high LCOE level is calculated. These areas are colored red in the heat maps in this section. On the other hand, attractive sites that have low LCOE values are colored blue/green.

Also included in the heat mapping are technological tipping points often resulting in step changes in LCOE. For example, going from a fixed bottom foundation to floating foundations where water depth is more than 60 meters.

The next sections present each step (sub-map) of the LCOE heat mapping, leading up to the final mapping result.

4.3.1 Wind resources

The Korea wind dataset of the Global Wind Atlas used for this analysis contains the wind speed potential at 100 meters above sea- and ground-level extending 200 kilometers from the Korean shoreline [37].

The data set was cropped to contain only wind speed offshore and within the Korean economic exclusion zone [127]. The resulting map of wind resources is given below in Figure 4-12 .

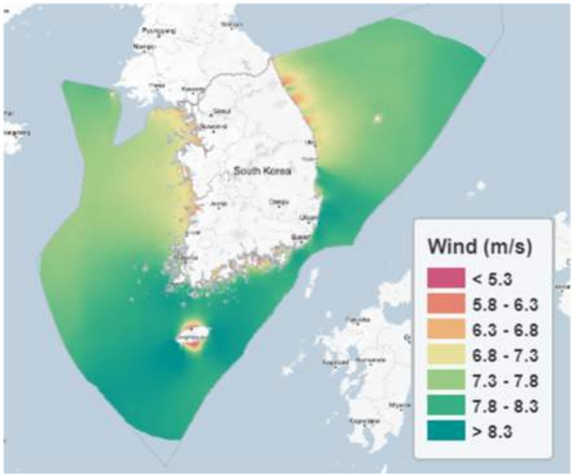


Figure 4-11: Offshore wind resources for Korea at 100 m [37]

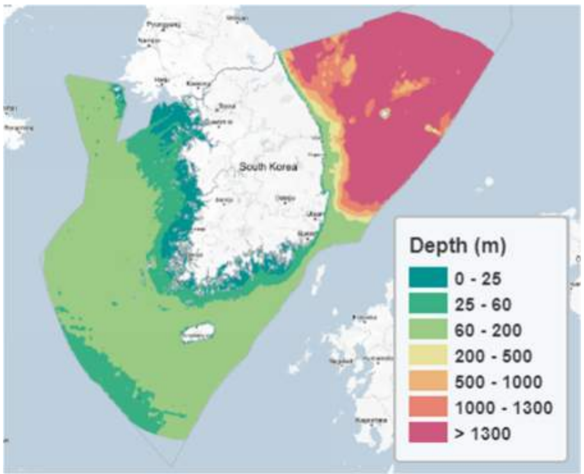


Figure 4-12: Bathymetry of the Korean seas [128]

4.3.2 Bathymetry

In this spatial-economic analysis, a feasible ocean depth for bottom-fixed wind farms up to 60 meters has been assumed. Above 60 meters, floating technology is thought to be the most cost-optimal choice [129].

Floating offshore wind is an emerging technology, where several design concepts are still being developed for commercial use; therefore, water depth limits are still being discussed. However, as water depth increases, cost increases as well from longer cables and mooring lines.

For this analysis, a maximum ocean depth of 2000 meters is assumed. This limit is not tied to any industry limit but provides a valuable boundary for the analysis.

Using criteria of the Korean economic exclusion zone boundary and ocean depths up to -1300 meters, the suitable water depth areas are shown in Figure 4-12.

This figure illustrates that those areas with a water depth of less than 60 meters are mainly found on the west coast, while heavily sloped and deep waters dominate the east coast.

4.3.3 Distance to ports

Korea has several large commercial harbors that possess the ability to support offshore wind construction. Stakeholder engagement has indicated that six different construction ports are likely suitable for installation of offshore wind farms. The six ports selected are Daesan, Gunsan, Mokpo, Busan, Ulsan and Pohang.

Location for the six ports was collected from the World Port Index [130].

Due to the limited amount of data in the World Port Index, the analysis makes no distinction between ports for bottom-fixed and floating, both for installation and O&M. Below, Figure 4-13 and Figure 4-14 show the distance to ports. The distance is a straight-line route without consideration of islands, military, or marine protected areas.

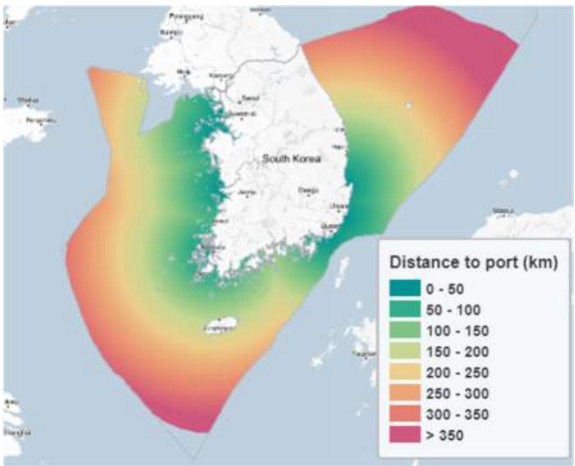


Figure 4-13: Distance to installation ports

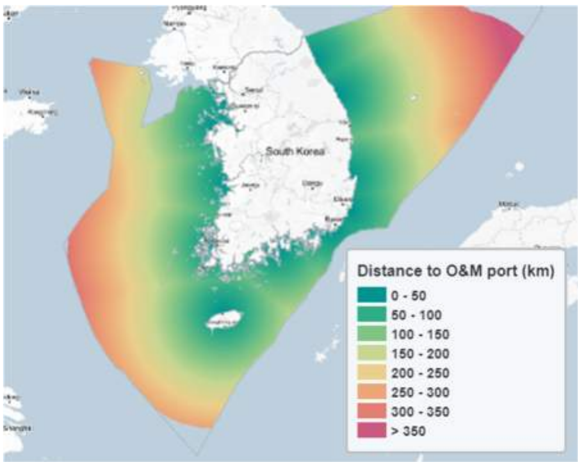


Figure 4-14: Distance to O&M ports

4.3.4 Distance to grid

The export cable length is used as an input to identify the cost of the transmission connection from the wind farm to an onshore connection point. The export cable is divided into an onshore and offshore section, which assume different characteristics. Data on the Korean electric grid is not open to the public due to national security. Thus, the offshore export cable length is calculated approximated by the distance to shore from each offshore location. A fixed length of 10 km from the cable landfall to an onshore grid connection point is assumed.

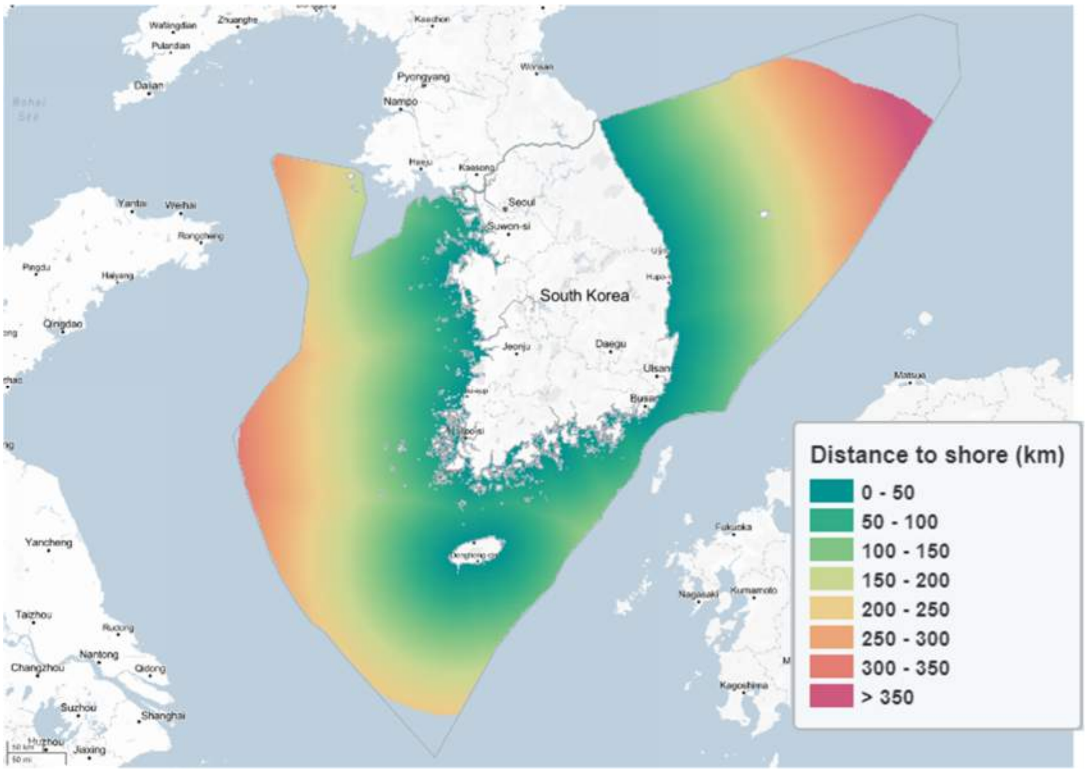


Figure 4-15: Distance to the shoreline of the main island and Jeju island

4.3.5 LCOE heat maps

The four maps presented in the previous sections are used to calculate LCOE heat maps for both, wind farms with bottom-fixed foundations and with floating foundations. Only the potential areas with average wind speeds over 7 m/s and water depth less than 60 m for fixed foundation and water depths from 60 m up to 1,300 m for floating foundation is considered. For bottom-fixed offshore wind, Figure 4-16 shows the lowest LCOE levels are found in the East China Sea close to shore, where wind speed is relatively high, transmission port distance is short, and water is shallow. Especially the east and west coast of Jeju island contain a high potential for wind farms as these areas have the best wind resources. Less competitive areas are found in the Yellow Sea, where the wind resources are less favorable.

For floating locations with water depth above 60 meters a strong correlation between the LCOE level and water depth outside the east coast can be seen in Figure 4-17.

Figure 4-16: LCOE map for fixed-bottom wind project locations (water depth ≤60m and wind speeds ≥7 m/s, partnership scenario)

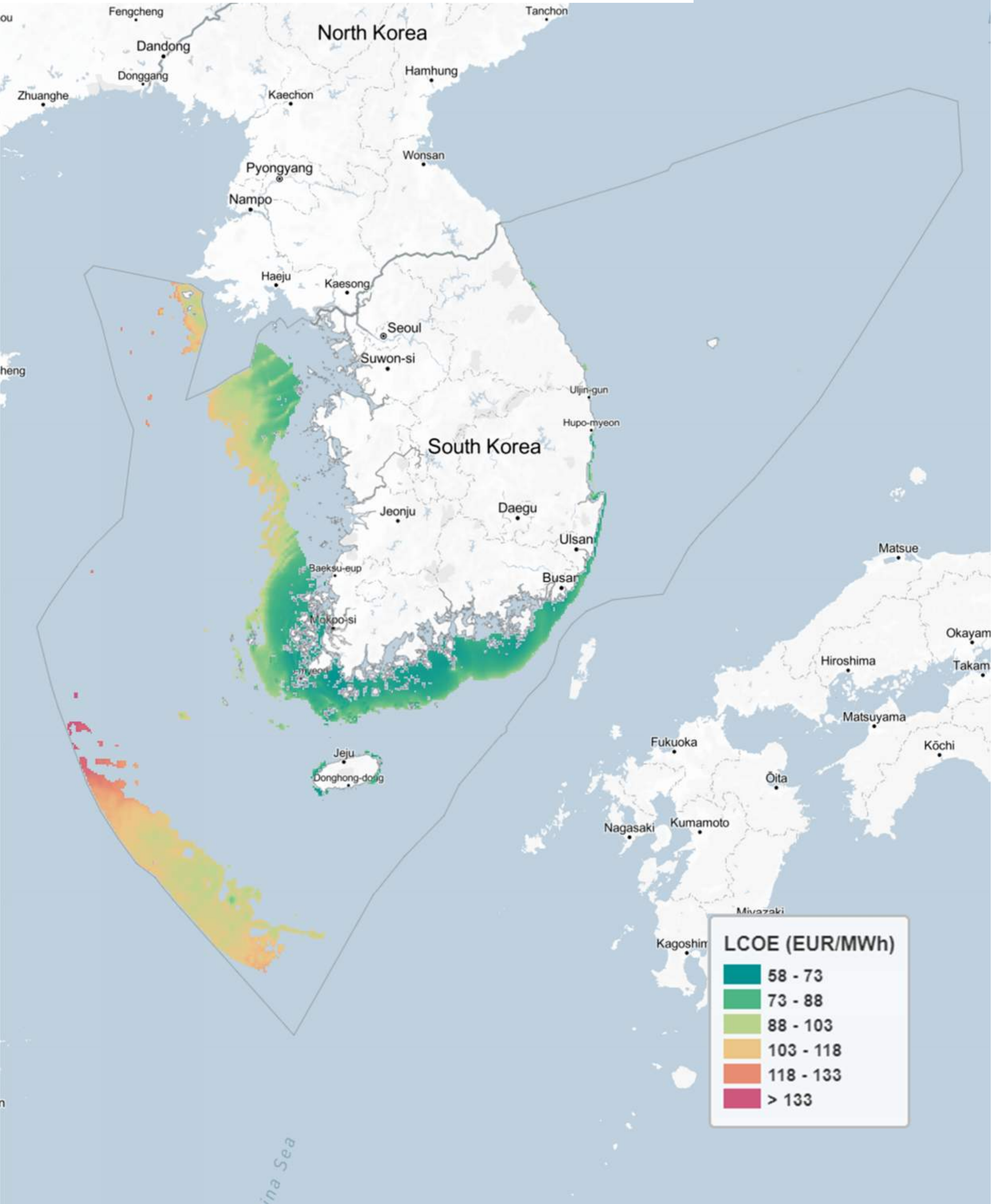
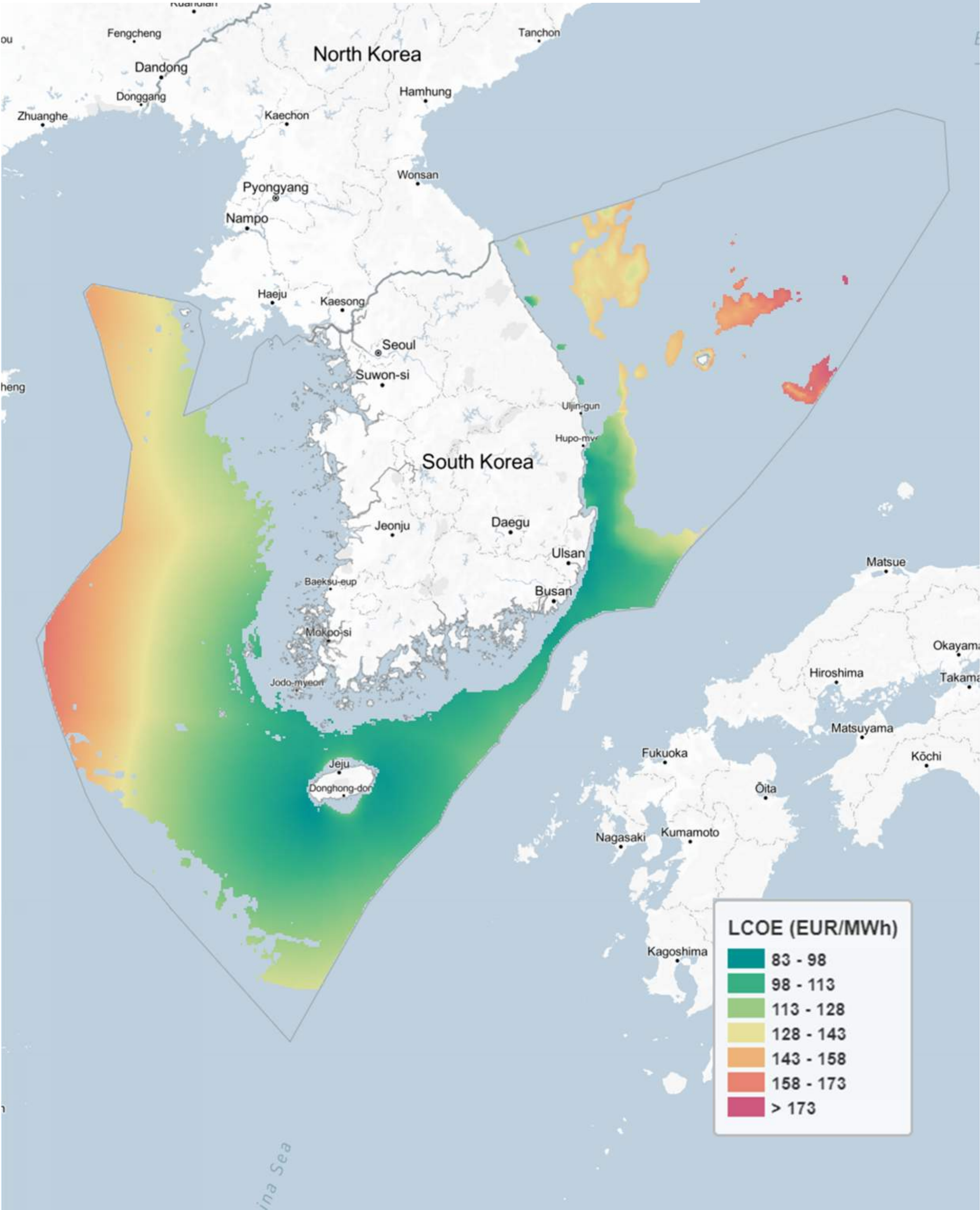


Figure 4-17 LCOE map for floating wind project locations
(water depth 60-1300m and wind speeds ≥7 m/s, partnership scenario)



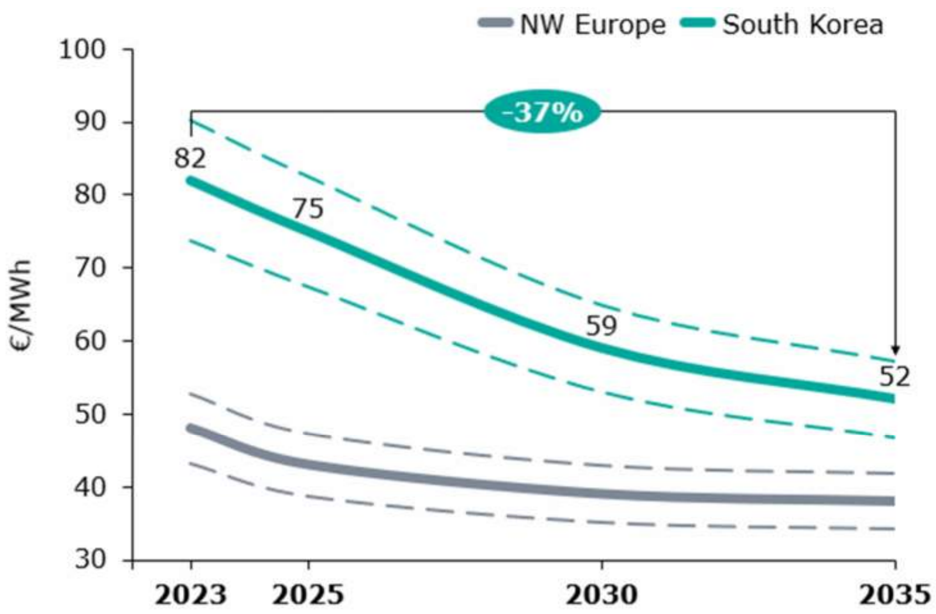
4.4 Cost-reduction trajectory towards 2035

The LCOE trajectory for fixed-bottom offshore wind projects in Korea from first commercial scale projects in mid-2020s, projected out to 2035, compared to mature projects in Europe are shown below in Figure 4-18:

LCOE for fixed-bottom wind projects is estimated to fall from ~80 EUR/MWh in 2023 to ~50 EUR/MWh in 2035, a reduction of close to 40%. This is based on the following assumptions:

- Low wind regime turbine size is expected to increase to 14 MW in 2035
- LCOE levels are dependent on a successful commercial build-out and a maturing domestic supply chain.
- Grid upgrades are not included in the LCOE estimates, which is especially important if grid upgrades would be needed
- High wind regime turbine size is expected to increase to 18 MW in 2035
- The declining cost of wind turbines and foundations, along with the efficiency improvements in installation and technology, reduce cost

Although the fixed-bottom LCOE in Korea is expected to decrease by almost 40%, the LCOE is not expected to reach European levels, as Europe has better wind conditions and is a global pioneer of wind energy.

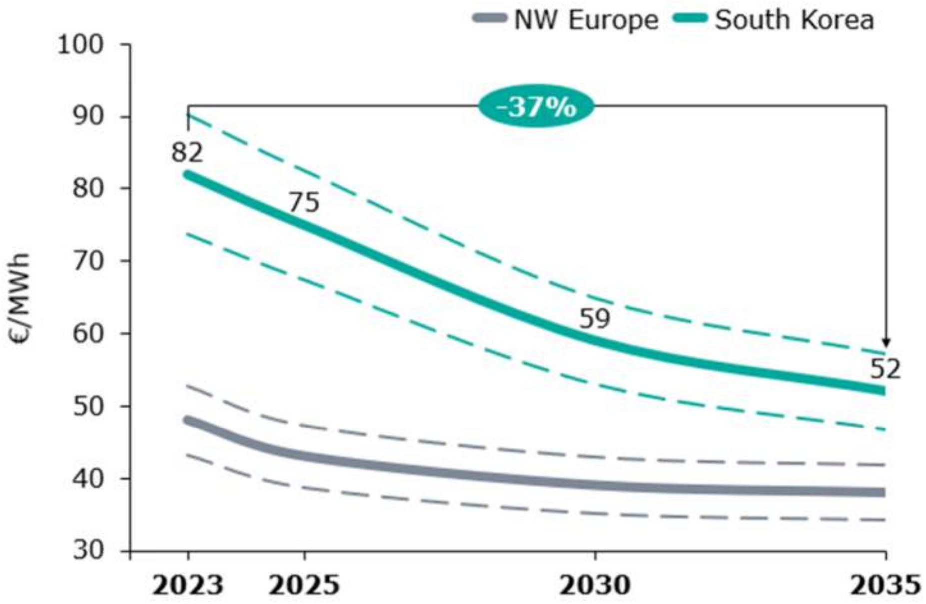


		2023	2025	2030	2035
Park (MW)	South Korea	225	400	750	1400
	NW Europe	740	1000	1500	2000
Turbine (MW)	South Korea	9	11	12.6	14
	NW Europe	14	15	18	20
Rotor (m)	South Korea	220	230	260	275
	NW Europe	222	236	260	275

Figure 4-18: LCOE forecast towards 2035 for fixed-bottom wind projects.

LCOE for floating wind projects is estimated to fall from ~110 EUR/MWh in 2025 to ~60 EUR/MWh in 2035, as shown in Figure 4-19.

Floating wind will benefit from many of the same cost reduction assumptions as in fixed-bottom technology. However, a higher LCOE is expected for floating wind in 2035 as this technology remains less mature.



		2023	2025	2030	2035
Park (MW)	South Korea	225	400	750	1400
	NW Europe	740	1000	1500	2000
Turbine (MW)	South Korea	9	11	12.6	14
	NW Europe	14	15	18	20
Rotor (m)	South Korea	220	230	260	275
	NW Europe	222	236	260	275

Figure 4-19: LCOE forecast towards 2035 for floating wind projects.

4.5 LCOE in context

Korea Power Exchange is in charge of operating Korea's wholesale power market and power systems, real-time power supply operations, and assists MOTIE in the establishment of the Basic Plan for Long-term Electricity Supply and Demand in Korea. When a power generation company produces electricity, it is purchased by KEPCO in the electricity market operated by Korea Power Exchange and sold to the final purchaser, the electricity consumer. LCOE is estimated as the cost (in KRW) that power providers receive from KEPCO (through the Korea Power Exchange) divided by the amount of generated electricity (in kWh).

LCOE varies greatly by the generation sources and among them, coal, oil and LNG are most affected by fluctuations in fuel costs. Figure 4-20 below, shows the historical trends of LCOE per year from 2011-2020.

According to KEPCO, the average LCOE per generation source for 10 years are 54.4, 73.4, 195.7, 130.8, 146.5 and 114.6 KRW/kWh for nuclear, coal, hydro, gas and renewable energy, respectively [131].

While it is not possible to compare the historical LCOE of existing energy sources with the LCOE predictions for offshore wind made in this study, it can be concluded that offshore wind most likely will become a commercially competitive energy source when commercial scale deployment has been obtained by 2035 and onwards.

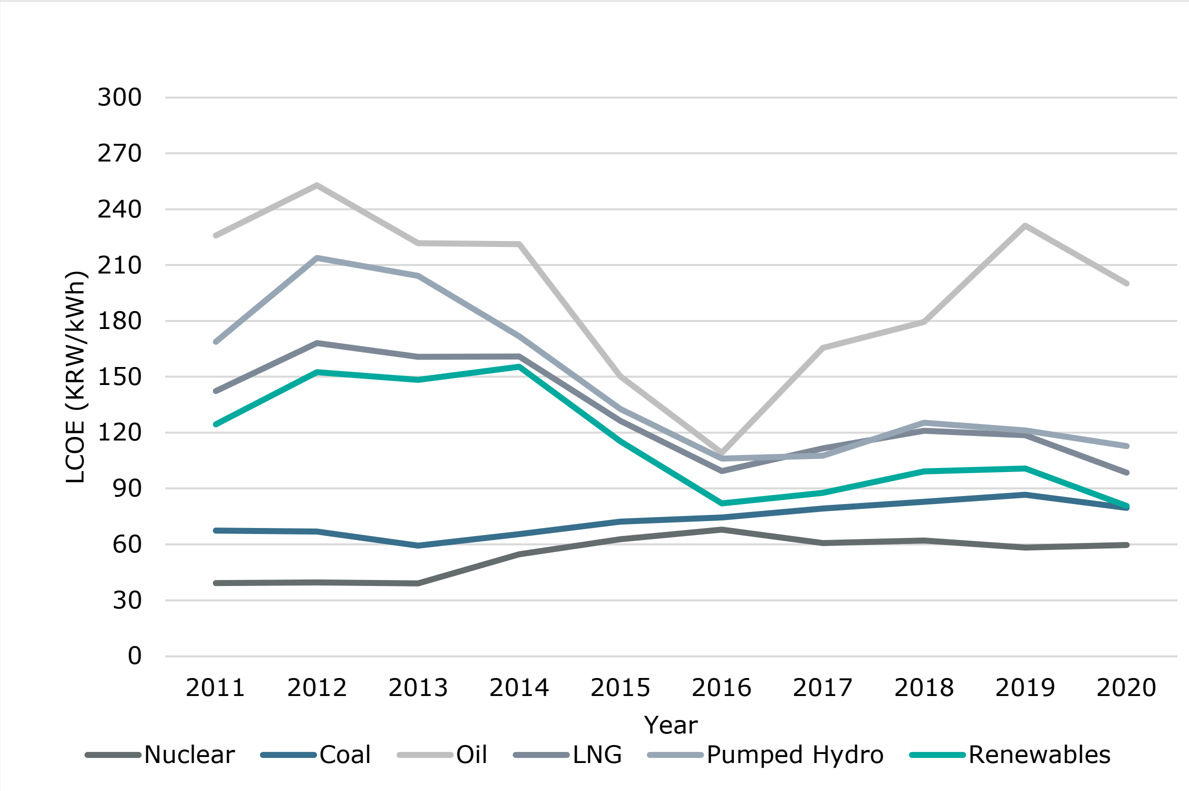


Figure 4-20: LCOE per generation source in the last 10 years (unit: KRW/kWh) [131]

4.6 Summary

The value heat mapping of the fixed-bottom and floating wind potential in Korea shows attractive locations for deployment towards realizing the 12 GW target by 2030. By combining key LCOE drivers as wind speed, water depth, distance to ports, and distance to grid connection, the best sites for fixed-bottom wind deployment are found in the south close to shore, where wind speed is relatively high, transmission port distance is short, and water is shallow. Waters around Jeju Islands are attractive having the best wind resources. For floating locations with water depth above 60 meters the lowest LCOE levels can be seen of the east coast and around Jeju Islands

LCOE assessments of the selected four promotion regions are based on commercial scale offshore wind project of 500 MW with COD in 2026. To reflect the impact of an emerging local supply chain for offshore wind in Korea, the two scenarios were assessed in each of the four promotion regions: Incheon, South Jeolla, Ulsan and Jeju Islands. Performing the wind farm economic analysis with a COD in 2026 requires the definition of a generic domestic turbine and a generic foreign turbine, which were confirmed through outreach to OEMs and developers. For foundation technology, monopiles are assumed to be deployed for water depths of 50-55 meters which are found in Incheon and South Jeolla. For water depths of 60 meters and above which are found in Ulsan and Jeju Islands, a generic semi-submersible floating substructure assembled onshore and towed to site is assumed. Cables and substations are assumed to be standard industry technology sourced locally.

The LCOE assessments results range from 75 to 95 EUR/MWh for fixed-bottom sites and from 101 to 116 EUR/MWh for floating sites for 2026 deployment across the four locations and the two supply chain scenarios. Going from partnership scenario to the domestic scenario for bottom-fixed sites are LCOE difference of 22% is seen, and for floating sites a change of 19% LCOE is seen primarily driven by the switch to the domestic turbine.

Furthermore, the potential delivery risk value related with a new turbine platform is assessed. In case an 8 MW turbine is not available in the mid-2020s, developers would have to rely on the second-best local option, a 5.56 MW offshore turbine with a rotor diameter of 140m. Approximating the value of the potential financial increase through an LCOE approach, EUR 1.25 billion is lost due to the increased LCOE of the second-best option.

Lastly, the LCOE trajectory for fixed-bottom and floating off-shore wind projects in Korea from is projected out to 2035. LCOE for fixed-bottom wind projects is estimated to fall from ~80 EUR/MWh in 2023 to ~50 EUR/MWh in 2035, a reduction close to 40%. For floating wind projects LCOE is estimated to fall from ~110 EUR/MWh in 2025 to ~60 EUR/MWh in 2035, equal to more than a 40% reduction. The reductions assume a commercial scale build-out and a quickly maturing local supply chain. Expected increase in turbine size and declining cost of turbine and foundation supply will drive down costs, as well as efficiency improvements in installation and technology.

Photo: COWI

5

EMPLOYMENT EFFECTS

5 Employment Effects

Korea's offshore wind target is intended not only to turn the conventional energy system in a low-carbon, renewable system, but also to create jobs. This section looks at the jobs expected to be generated by the four reference cases in each scenario and offers recommendations for making the most out of offshore wind's job creation potential.

To calculate the employment effects of investments like those described for the four reference sites, COWI uses a model based on local data of input and output between the industries, domestic productivity and salary levels. This economic model calculates the total employment effects from the different scenarios in each of the four reference sites: Incheon, South Joella, Jeju Island and Ulsan.

5.1 Economic impact calculations

The calculations are based on employment induction coefficients provided by the Ministry of Employment and Labor of the Republic of Korea [132]. The employment induction coefficients (EIC) include both the direct and indirect employment effects and quantifies the number of full time equivalent (FTE) years generated by an increase in economic activity within a specific sector. The total employment effect is calculated by multiplying the investments of the different scenarios with the chosen sector's employment induction coefficients.

An FTE year corresponds to one individual working full time for a year. Thus, FTE years are not jobs. A person employed in a fulltime job for 20 years will generate 20 FTE years but only one job. Jobs are generated when FTE years are delivered concurrently, i.e. delivering 200 FTE years in one year generates 200 jobs.

5.1.1 Assumptions

The model calculations are based on the estimated CAPEX and OPEX for the two scenarios in each of the four reference sites. The following tables summarize the CAPEX and OPEX estimates as given in Appendix C. The OPEX, which is the operating expenditures for the entire lifetime of the wind farm, is assumed to be 100% domestic.

Table 5-1 CAPEX and OPEX for Incheon reference site (bottom-fixed foundation)

Incheon				
	**Total CAPEX (mil. EUR)**	**Total OPEX (mil. EUR)**	**SUM (mil. EUR)**	**Domestic share of total lifetime cost**
Partnership scenario	1,714.2	776.6	2,491	68%
Domestic scenario	1,841.7	714.7	2,556	100%

Table 5-2 CAPEX and OPEX for South Jeolla reference site (bottom-fixed foundation)

South Jeolla				
	**Total CAPEX** (mil. EUR)	**Total OPEX** (mil. EUR)	**SUM** (mil. EUR)	**Domestic share of total lifetime cost**
Partnership scenario	2,032.0	784.3	2,816	65%
Domestic scenario	2,268.7	720.4	2,989	100%

Table 5-3 CAPEX and OPEX for Jeju Island reference site (floating foundation)

Jeju Island				
	**Total CAPEX** (mil. EUR)	**Total OPEX** (mil. EUR)	**SUM** (mil. EUR)	**Domestic share of total lifetime cost**
Partnership scenario	2,432.6	763.2	3,196	82%
Domestic scenario	2,524.0	704.9	3,229	100%

Table 5-4 CAPEX and OPEX for Ulsan reference site (floating foundation)

Ulsan				
	**Total CAPEX** (mil. EUR)	**Total OPEX** (mil. EUR)	**SUM** (mil. EUR)	**Domestic share of total lifetime cost**
Partnership scenario	2,654.2	763.2	3,417	83%
Domestic scenario	2,754.4	704.9	3,459	100%

In the guidance document on employment effects published by the Ministry of Employment and Labor of the Republic of Korea, the employment induction coefficients are categorized in 34 main sectors [132]. The construction and operation of an offshore wind farm does not have a perfect match with any one sector. Consequently, a weighted average of the construction, water transport and manufacturing sectors is used. The weights are approximations based on experience and review of the Korean supply chain. The model assumes that the sectors contribute to the construction and operation of the wind farms according to the weights below in Table 5-5.

Table 5-5 Sector weight for the employment induction coefficient

Chosen sectors	**CAPEX Weight**	**OPEX Weight**
Construction	0.60	0.70
Water Transport	0.10	0.25
Manufacturing	0.30	0.05

CAPEX is expected to require a much larger component of manufacturing relative to OPEX. OPEX, on the other hand, is expected to require a larger component of water transport as transport to and from the wind farm will be a substantial cost component in the O&M phase. The coefficients of the three relevant sectors are presented in Table 5-6, below.

Table 5-6 Extract of table of Employment Induction Coefficients [132], converted to EUR using currency rate in Section 1.

Classification by industry	**EIC** (Per person/100 million won)	**EIC** (Per person/EUR)
Construction	0.82	0.0000109434
Water transport service	0.24	0.0000032029
Manufacturing and industrial equipment repair	0.79	0.0000105430

Employment induction coefficients will differ from one country to the next due to differences such as salary levels, productivity, general economic development and labor market regulation. This model only estimates the employment effects for the economic activity expected within Korea, i.e. the domestic shares reported in Table 5-1 to

Table 5-4.

5.1.2 Results

The following four tables present the total employment effects for the reference sites and corresponding scenarios. The CAPEX is split between domestic and foreign share of the investment, while the OPEX is all assumed to be all domestic contribution.

The highest Korean job creation for Incheon is achieved with the domestic scenario, with CAPEX of EUR 1,841 mil. and OPEX EUR 715 mil, see Table 5-2. Over the lifetime of the project, the wind farm is expected to generate almost 25,000 FTE years of domestic work in Korea. The peak job creation will happen during construction, where more than 18,000 FTE years will be delivered within a few years.

For Incheon, the domestic scenario is expected to generate 53% more FTE years than the partnership scenario. This is due to the domestic share growing from 54% in the partnership scenario to 100% in the domestic scenario.

In general, the domestic scenario is expected to generate the most Korean jobs across all four sites. The results for each site are shown in Table 5-7-Table 5-10, below.

Table 5-7 Incheon – Korean employment effects based on scenarios

Incheon			
	**FTE from CAPEX**	**FTE from OPEX**	**Total domestic FTE**
Partnership scenario	9,116	6,962	16,079
Domestic scenario	18,219	6,407	24,626

For South Jeolla the domestic scenario is expected to generate close to 29,000 FTE years of Korean employment. More than 22,000 FTE years are expected to be required during construction. A comparison of the two bottom fixed wind farms shows that South Jeolla will likely generate a higher share of domestic activity across all three scenarios. In the domestic scenario, South Jeolla is expected to generate more than 4,000 extra FTE years compared to Incheon. This is a 17% difference, which is quite significant.

Table 5-8 South Jeolla – Korean employment effects based on scenarios

South Jeolla			
	**FTE from CAPEX**	**FTE from OPEX**	**Total domestic FTE**
Partnership scenario	10,315	7,031	17,346
Domestic scenario	22,443	6,458	28,900

For Jeju Island the domestic scenario is expected to generate more than 31,000 FTE years of Korean employment, of which almost 25,000 will be realized during construction, with CAPEX of EUR 2524 mil. and OPEX of EUR 705 mil, see Table 5-4.

For the two floating foundation wind farms, the increase in domestic job creation from the partnership scenario to the domestic scenario is expected to be close to 6,000 FTE years or 24%.

Table 5-9 Jeju Island – Korean employment effects based on scenarios

Jeju Island			
	**FTE from CAPEX**	**FTE from OPEX**	**Total domestic FTE**
Partnership scenario	18,419	6,842	25,261
Domestic scenario	24,968	6,319	31,287

For Ulsan, the domestic scenario is expected to generate almost 34,000 FTE years of Korean employment, and more than 27,000 FTE years during construction. Of the two floating wind farms, Ulsan is expected to deliver the greatest domestic job creation. The difference between Jeju Island and Ulsan in the domestic scenarios is expected to be 2,300 FTE years or 7%. This is likely not a significant difference.

Table 5-10 Ulsan – Korean employment effects based on scenarios

Ulsan			
	**FTE from CAPEX**	**FTE from OPEX**	**Total domestic FTE**
Partnership scenario	20,611	6,842	27,452
Domestic scenario	27,247	6,319	33,566

In an international context, these numbers are in line with findings in other studies. The Institute for Sustainable Futures, on behalf of Greenpeace, estimates the direct job creation within offshore wind, i.e. not including indirect effects which are also considered in this report [133]. In this estimation, construction and manufacturing is estimated to generate 23.6 job years (same as FTE years) per MW while O&M generates 0.2 job years per MW per year over the lifetime of the project. For a 500 MW offshore wind farm this corresponds to 11,800 FTE years during construction and 2,500 FTE years more during O&M for a total of 14,300 FTE years. The Greenpeace study also indicates that indirect employment typically accounts for an additional 50% to 100% FTE years. Thus, the total direct and indirect employment effect sums to between 21,000 and 28,000 FTE years, which is similar to the results in this study.

In a QBIS study from 2020, the Danish direct and indirect employment effect of future planned offshore wind farms in Denmark is estimated [134]. The results show a direct and indirect employment effect per GW installed capacity of 9,500 FTE years or 4,750 FTE years per 500 MW. These estimates are based on a quite aggressive assumption about the development in FTE/CAPEX. It is assumed that technological development means that fewer hands are required for the construction of offshore wind farms. The domestic share of total employment is also lower in Denmark than what is expected in South Korea. Finally, salary levels in Denmark are 2-3 times higher than in Korea [135]. Consequently, FTEs are expected to be higher in Korea as the Korean employment induction coefficients are approximately 3 times higher than the Danish coefficients.

5.2 Extrapolation of representative results up to 12GW

In addition to looking at the project level economic impact, it is also helpful to examine the larger impact of offshore wind energy at a national level.

An increase of the offshore wind power capacity to 12 GW by 2030 can be modelled in a simple way by proportionally expanding the capacity of the current reference sites. This simulates a mix of locations in the country and foundation types. The current installed capacity is disregarded in this calculation. Under these assumptions, the total Korean in FTE develops as seen in Figure 5-1.

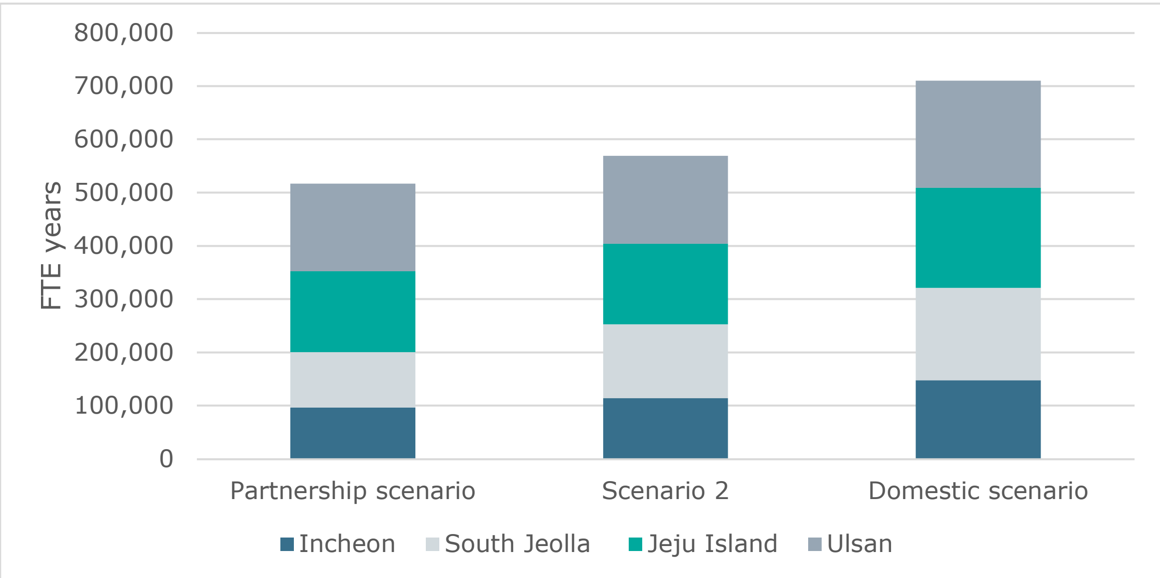


Figure 5-1 Extrapolation of total Korean FTE to 12 GW by proportionally applying reference cases

As the level of the domestic share of the construction work increases, so does the total Korean employment effect. In the partnership scenario of the reference projects, 65-68% or 82-83% of the supply is domestic, for fixed-bottom and floating wind farms, respectively.

In the domestic scenario 100% of the supply chain is domestic. As discussed in Chapter 3, there will likely be short and mid-term domestic supply chain shortages if capacity is quickly increased to 12 GW. In a fast-paced ramp-up, it may also be difficult for the development of the Korean offshore wind industry to keep up and provide the necessary qualified labor.

The ability of the domestic infrastructure to meet the demand for technology and labor depends on how fast the increasing capacity is implemented. If the implementation is too fast, the local content will likely be low, as the domestic supply cannot keep up with the demand, e.g. corresponding to the partnership scenario. The domestic scenario is an illustration of a slower implementation where the domestic market is allowed time to expand its capacity and cover the full demand.

If the domestic scenario can be achieved, it will provide a 38 % increase in domestic FTE years over the partnership scenario.

5.3 Economic recommendations for value capture and long-term retention

Offshore wind is experiencing global and increasing pressure to deliver energy at lower and lower costs. At the same time, the countries where the wind farms are being installed are increasingly aiming to profit from the manufacturing and installation of the wind farms, as well as the lower energy cost. In that quest, local content requirements (LCR) have become a popular political tool used to achieve this goal.

From an economic standpoint, LCR are controversial because they are essentially a limitation on free trade. A common criticism of LCR is that they lead to higher energy prices, as wind farms are forced to purchase at a higher price than the global market rate and these costs are eventually passed on to the electricity consumer. Another criticism is that LCR can lead to economic booms and subsequent busts in certain sectors, are these sectors are favored under the LCR, but not globally competitive when the LCR is removed.

If given free choice of global supply chain, wind farm developers will naturally optimize for lowest LCOE. Therefore, it is not the case that the offshore wind supply chain necessarily localizes to 100% in countries with a mature OW industry. Especially low-technology components whose price is heavily tied to commodity prices such as steel can be easily re-located to deliver the lowest price. This was seen recently, when French energy giant EDF decided to have most of the jackets for its Scottish Neart na Gaoithe wind farm (450 MW) produced in Indonesia, instead of in Scotland [136].

This report estimates that Korea can already provide minimum 65% local content. In global comparison, this is already in the top league. The UK, one of Europe's market leaders, has achieved close to 50% local content after installing 10.2 GW and have now set a target for some 60% [137]. Achieving the level of local content suggested in the domestic scenario requires careful planning and patience.

The choice of technologies to deploy can have an impact on the local content. Semi-sub floating foundations play to Korea's strengths as a steel manufacturer and are prime candidates for export, as they can be type certified. Focusing the development of offshore wind farms in Korea on floating foundation sites could contribute to enhancing local job creation and strengthening Korean exports.

Another aspect that may impact local job creation is the choice of wind farm size. There is not one single optimal size. Rather the optimal size will evolve as the Korean offshore industry develops. In a start-up phase, where local experience with offshore wind is limited, smaller sized wind farms may allow more – and equally important smaller - players to enter the market and gain experience. As the offshore wind industry in Korea gains traction, larger wind farms will provide the stability and volume for the industry to grow and consolidate.

In terms of recommendations for designing the optimal pipeline, it is recommended to aim for a stable pipeline rather than a fast and immediate growth. If the pipeline is kept stable, the sector will also remain in work and the steadier growth will have a more long-term effect on the economy, rather than a temporary effect of quick growth which then afterwards leaves the sector unemployed for longer periods of time. A stable pipeline will also increase the likelihood of sustaining a local supply chain and thereby a high share of local content.

5.4 Summary

Based on the model presented above, the total Korean employment effects for the four reference sites will vary depending on the level of domestic supply content:

- Incheon: 16,079 FTE – 24,626 FTE
- South Jeolla: 17,346 FTE – 28,900 FTE
- Jeju Island: 25,261 FTE – 31,287 FTE
- Ulsan: 27,452 FTE – 33,566 FTE

These employment numbers are comparable to results from international studies, although differences in assumptions about future economic and technological development can have a substantial impact on the results, as seen in the QBIS study [134]. Assumptions on future automation of manufacturing and installation processes, differences in salary levels and differences in the domestic share of jobs leads to very low employment effects in Denmark relative to South Korea.

To increase the local share of the employment effects, it is necessary to look at the timing of the investments. If Korean suppliers are not able to meet the demand and provide the labor, it will be beneficial to employ foreign labor and import more technology. This is especially critical when looking at an ambitious plan for implementing large amounts of offshore wind in a short timeframe.

Creating a strong local supply chain is also heavily dependent on demonstrating political long-term commitment to a substantial pipeline. Manufacturing and installation of offshore wind is capital intensive and has a long payback time. If the local ambitions on offshore wind are perceived as unstable and likely to change frequently, then investments in a local supply chain will be deemed riskier.

Availability of local ports equipped for offshore installation and O&M can support the local job creation. The experience from Europe shows that the distance from the staging port to the wind farm is important but not critical during installation. It is more important during O&M. In both cases, closer is better, and providing well located and well-equipped ports will contribute to attracting installation and O&M activities to the country.

Technology choice also plays a role in supporting local job creation. Floating offshore wind is expected to play into Koreas strengths as a steel producer. Taking local manufacturing strengths and weaknesses into consideration when planning wind farm localization and design can contribute to increase the local job creation and strengthen exports.

OUTLOOK

6 Outlook

Korea is at the start of an exciting and ambitious journey into offshore wind. This study aims to support the goal of 12 GW by 2030 with a critical analysis of the status quo and to propose solutions to the challenges identified in the following areas:

- **Policy environment:** risk profile for developers is very high due to the lack of a unified permitting system, the open-door type project development and decreasing REC prices which pressure the revenue side of the business case.

- **Supply chain:** Korea is in an excellent starting position, but the wind farms which have been completed so far with the domestic supply chain also reveal the need for substantial improvements in installation times and efficiency. Most balance of plant can be provided by Korea, but some sectors especially will need to make capital investments in new equipment and additional capacity, such as vessels, while others will need to develop, e.g. XL monopile manufacturing. Turbine technology is key to the supply chain and the gap between global leaders, and domestic manufacturers is still large. In addition, stakeholder engagement has shown that the risks of using domestic turbines are often seen as prohibitively high. Finally, the size of wind farms must increase significantly from the current average of 180 MW in order to realize economies of scale and attract the global supply chain.

- **LCOE:** levelized cost of energy for floating sites is higher (98-120 EUR/MW) than the LCOE for bottom-fixed (75-95 EUR/MWh) due to higher costs of the floating foundation. Relaying only on the domestic supply chain results in 22% higher LCOE for bottom-fixed projects and 19% higher for floating. This difference equates to 870 million EUR (1.16 trillion KRW) in additional project costs for the 500 MW Incheon (fixed-bottom) reference site. These cost differences are driven largely by the use of a domestic turbine. There are also large delivery risks associated with developing a new turbine platform, as domestic suppliers are doing. While foreign suppliers can deliver a turbine very close to the generic one in this study already today, domestic manufacturers are in the inherently risky process of developing new platforms with a large jump in ratings. If developers commit to a domestic turbine and have to fall back on the next-best option, a 5.5 MW turbine, it could cost them 1.25 billion EUR over the life of a 500 MW project. On the other hand, if these supply chain challenges are addressed and the build-out gains speed, the LCOE levels are forecasted to drop ~40% from mid-2020 to 2035.

- **Employment effects:** this study confirms that offshore wind can support a high number of quality jobs. As FTE are linked to the amount invested, the domestic scenario is expected to generate the most jobs – 24,626 -33,566 FTE for the reference cases. However, a fully domestic scenario can likely be achieved only for a limited number of projects until 2030, given the current supply chain constraints. The partnership scenario generates 16,079-27,452 for the same reference cases, which is approximately 65%-80% of the jobs generated in the domestic scenario. In order to generate and retain as many high-quality jobs as possible, it is fundamentally important that the pipeline of work in offshore wind be kept stable. Boom and bust cycles are economically damaging and should be avoided. Both, domestic and foreign stakeholders will only invest into offshore wind, if the risks to finance and build these large infrastructure projects are backed by a clear and realistic policy roadmap. Large initial volumes in the early years and a steady predictable pace of subsequent procurements is essential for suppliers to justify investments in the supply chain and to attract additional supply chain participants.

Addressing challenges

The government of Korea already has plans to address some of the hurdles described above, such as:

- Implementing a clear and coordinated permitting process
- Lowering the developer risk profile
- Increasing wind farm size to secure economics of scale
- Establishing a stable and visible pipeline, also after 2030

The planned reforms and initiatives to address these issues should be swiftly and formally implemented. In addition to the above, this study has identified further areas of concern which are not adequately covered by existing plans and initiatives. Should Korea follow only the domestic scenario, it will face several key challenges:

- Timely commercialization of at least 8 MW domestic turbines with good performance and reliability
- Increase average domestic production capacity (MW/year) by 10x
- Increase average wind farm installation rate (MW/month) by 20x
- Likely bottlenecks in installation vessels
- Hiring and qualification of laborers for manufacturing, installation and service
- Massive ramp-up of capacity in weaker parts of the domestic supply chain, like project development, XL monopiles, turbine installation and monopile installation

These challenges communicate a clear message: if Korea continues to follow the status quo, there is a high risk of missing the 2030 12 GW goal for offshore wind. In addition, the offshore wind farms that are built will be constructed slower and at a 19-22% higher cost than in the partnership scenario.

Partnership benefits

A natural and effective way to overcome these hurdles is by forming foreign-domestic partnerships which can:

- Provide proven wind turbine technology from global leaders
- Ramp up procurement from domestic supply at a sustainable rate for suppliers, both in terms of capital investments and labor qualification
- Support educational capacity building and labor qualification
- Increase wind farm installation rate using experienced crews and vessels
- Provide training and knowledge transfer opportunities on state-of-the-art wind farms

Good partnerships are powerful engines which can propel companies forward together. The domestic partner smooths the way into the market with its local knowledge and the foreign partner transfers knowledge and technology. The result is that Korean companies can leapfrog to best-in-class. The country of Korea benefits from having a faster build-out of offshore wind with higher efficiency and lower cost.

The way a partnership looks is likely to change over time. Partnerships are dynamic and can be adapted per sector and over time, as domestic capability and capacity grows. Project development, for example, will be a key partnership. At the beginning of a collaboration, the support from the foreign side would likely be more extensive with a focus on knowledge transfer and establishing cooperation. Over time as the Korean partners gain first-hand experience, the balance is expected to shift towards more expertise and personnel on the domestic side.

The wind turbine will be the other key partnership. Unlike project development, turbines have a large manufacturing component that must be addressed. While Korea is in an excellent position to provide significant amounts of components to the turbine, ramp-up of complex manufacturing processes takes time. Partnerships can make the most of Korea’s capability and capacity and strategically increase it over time.

This study has chosen to use two scenarios to conduct its analysis, but in practice it will be a spectrum rather than a binary choice. Some partnerships could have the goal of supporting domestic turbine manufacturers and increasing their competitiveness through experience. Some projects could be built with a larger proportion of foreign supply due to domestic constraints. On the whole, increasing the involvement of the mature offshore wind supply chain in Korea will best serve the goal of 12 GW by 2030.

> The partnership supply chain can bring the speed and lowest cost, while at the same time putting Korean partners on the fast track to global-level competitiveness.

7 ABBREVIATIONS

7 Abbreviations

Abbreviation / Acronym	Term
BOP	Balance of plant
CAPEX	Capital expenditure
COD	Commercial operation date
CTV	Crew transfer vessel
DEA	Danish Energy Agency
EBL	Electric Business License
EIC	Employment induction coefficient
GE	General Electric Renewable Energy
GENCOs	State-owned power generation companies
FTE	Full time equivalent
KEPCO	Korean Electric Power Corporation
LCOE	Levelized cost of energy
LCR	Local content requirement
MOE	Ministry of Environment
MOF	Ministry of Oceans and Fisheries
MOTIE	Ministry of Trade, Industry and Energy
OEM	Original equipment manufacturer
OPEX	Operational expenditure
O&M	Operation and maintenance
PPA	Power purchase agreement
RE3020	Renewable Energy 3020 Implementation Plan
REC	Renewable energy certificate(s)

RPS	Renewable Energy Portfolio Standard
RVO	Netherlands Enterprise Agency
SGRE	Siemens Gamesa Renewable Energy
SMP	System Marginal Price
SOV	Service operation vessel
SPV	Special purpose vehicle

8

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Photo: Vestas

9

APPENDICES

9 Appendices

Appendix A List of Electric Business Licenses issued for offshore wind

List of EBL issued for offshore wind (as of March 2021) [6]

License No	Project	Developer	Capacity (kW)	Date acquired
02016-76	Shinan Jeungdo	Win Wind Power	33,000	30-Oct-2019
2015-165	Saemangeum Offshore	Saemangeum Offshore Wind Power	98,800	13-May-2019
2016-073	YoungGwang Doouri	Jewon Energy	99,100	31-May-2016
2017-007	Tong Young Socho	Young Dong Development	9,900	28-Dec-2020
2017-050	Yeomsan	Daemyeong GEC	38,400	07-Feb-2018
2017-052	Abhae 1	Abhae Wind Power	40,000	26-Feb-2020
2017-053	Abhae 2	Abhae Wind Power	20,000	26-Feb-2020
2017-065	Jeonnam Shinan Jaeundo	SK E&S	96,000	31-Jul-2018
2017-083	Busan Haegi cheongsapo	G Wind Sky	40,000	02-Dec-2019
2017-084	Jeonam Shinan 1	POSCO Energy and KOEN	300,000	31-Aug-2018
2018-018	Wind Turbine Test Bed	Jeonnam Techno Park	12,300	20-Nov-2018
2018-075	Southeast Coast	SK E&c	136,000	21-Sep-2018
2018-081	YoungGwang Yawol	Daehan Green Energy	49,800	21-Sep-2018
2018-082	Chilsan	CWNRE	151,200	21-Sep-2018
2018-100	Jeonam Wando	Wando Offshore Wind Power	148,500	19-Jul-2019
2018-101	Wando Geumil	KOEN and KOSEP	200,000	21-Nov-2018
2019-009	YoungGwang Nakwoel	Myungwoon Development	354,480	30-Jan-2019
2019-018	TongYoung Yokji	Yokji Wind Power	352,000	26-May-2020
2019-033	Anmado	Anma Offshore Wind Power	224,000	27-Jul-2020
2019-036	Shinan Ui	Hanhwa E&C, SK D&D and KOEN	396,800	02-Jul-2019
2019-037	Shinan Eoul	Shinan Eoul Wind Power	99,000	02-Mar-2021
2019-076	Ansan Pungdo	Seohae Green Power	200,000	19-Jul-2019

License No	Project	Developer	Capacity (kW)	Date acquired
2019-090	YoungGwang Yaksu	Jeonnam Development Corporation	4,300	30-Oct-2019
2020-038	Cheinsaeoui	Cheinsaeoui Offshore Wind Power	99,000	02-Mar-2020
2020-039	YoungGwang Yawol 2	YoungGwang Yawol 2 Offshore Wind Power	10,000	27-Apr-2020
2020-046	Jeonam Offshore Wind	SK E&S	96,000	27-Apr-2020
2020-049	Haenam Maewol	Haenam Maewol Offshore Wind Power	96,000	26-May-2020
2020-055	Busan Offshore Wind Power	Busan Offshore Wind Power	96,000	27-Jul-2020
2020-056	Anmado	Anma Offshore Wind Power	304,000	27-Jul-2020
2020-065	Jeonnam Yeosu Samsan	Samhae Development	288,000	22-Sep-2020
2020-069	Incheon Ongjin	C&I Leisure	233,500	22-Sep-2020
2020-089	Jeonnam Yeosu Samsan	Jeonnam Yeosu Samsan Offshore Wind Power	320,000	30-Nov-2020
2020-090	Jeonbuk Gochang	Dongchon Wind Power	69,300	30-Nov-2020
2020-092	Jeonnam YoungGwang	Jeonnam Techno Park	8,000	18-Dec-2020
2020-130	Chungnam Dangjin	Wind Way	210,000	30-Nov-2020
2021-001	Korea Offshore Wind Power	Korea Offshore Wind Power	400,000	02-Feb-2021
2021-002	Sinan Daegwang Offshore Wind Power	Sinan Daegwang Offshore Wind Power	400,000	02-Feb-2021
2021-003	Geumil Offshore Wind Power	KOEN	400,000	02-Feb-2021
2021-006	Jeonnam Shinan Jaeundo	SK E&S	399,000	02-Feb-2021
2021-009	Taean Wind Power	Taean Wind Power	504,000	02-Mar-2021
2021-014	Jeonnam Shinan Jaeundo	SK E&S	399,000	02-Feb-2021
2021-015	Gunghang Offshore Wind Power	Gunghang Offshore Wind Power	240,000	02-Mar-2021

Appendix B Supply chain of Southwest Sea offshore wind demonstration site

Supply chain of Southwest Sea offshore wind demonstration site

Wind Turbine/ Substructure	Detailed design of Substructure structure	Doosan Heavy Industries & Construction (Seil Eng.)
	Wind Turbine Production	Doosan Heavy Industries & Construction (Nacelle, Hub: Doosan Heavy Industries & Construction) (Blade: Human Composite, Tower: Win&P/Dongkuk S&C)
	Fabrication/ Installation of substructures Wind Turbine installation	Hyundai E&C (Substructures production/upper installation: Hyundai Steel Industry) (Substructures installation: Gwanak Industry) [R&D substructures: KEPRI (Advact), POSCO (Hyundai Steel)]
Offshore substation	Foundation/upper structure	KEPCO (Fabrication/Installation: Hyundai Steel Industry)
	Substation equipment supply/installation	KEPCO (Transformer: Hyundai Heavy Industries) (23kV GIS: Intec, 154kV GIS: LSIS)
Subsea cable	Export cable	KEPCO (Fabrication: Sumitomo, Installation: Seacheon)
	Inner array (R&D 3 TBs)	KERI (Fabrication: Taihan, Installation: KOCECO)
	Inner array (17 TBs)	KEPCO

		(Fabrication: Taihan, Installation: KOCECO
Project management	Construction project management (supervisory agency)	KECC/Shinhan A&E
	Owners Engineering	Yooshin
	Project certification	Korean Register of Shipping
License	Licensing support	Sekwang Eng.
	Marine environment and basic ecological survey	Sekwang Eng.
Fishery compensation	Consignment and entrustment of compensation	Korea Appraisal Board
	Fishery damage investigation	Chonnam National University Fisheries Science Research Institute
	Fishery right appraisal	Daeil Appraisal Board, Onnuri Appraisal Corporation
Project Financing	Financial Advisory	Woori Bank
	Advisory for business owners	Jipyeong, KISTEP, K2M
	Business Feasibility Analysis	Sejong, DNV-GL, Marsh Korea
Construction insurance	Insurance company	Hyundai Marine & Fire Insurance, etc.
	Reinsurer	Swiss Re, etc.
	MWS	LOC

Appendix C Cost percentage breakdown for bottom-fixed and floating reference sites

A percentage lifetime cost breakdown of categories as calculated for the reference cases.

Category		**Category split**	**%, Bottom-fixed wind farm**	**%, Floating wind farm**
Project development		DEVEX scaled on wind farm size, based on market maturity level	1-2%	1%
Turbine supply and installation		Supply Installation	20-23%	17-18%
Foundation supply	Bottom-fixed	Monopile and transition piece supply Jacket and pile supply	10-16%	-
	Floating	Floater supply Onshore assembly Mooring supply	-	31-33%
Foundation installation	Bottom-fixed	Monopile installation Transition piece installation	4%	-
	Floating	Mooring installation Floater installation (towing by tugboats)	-	1%
Array cable supply and installation		Array cable supply Array cable installation	3%	3-4%
Transmission & grid		Transmission (onshore and offshore substations, export cables) Grid costs SCADA	16-17%	9-13%
Operation & Maintenance		Operation and maintenance cost Owner's cost, Logistics cost, Operations cost	25-28%	20-21%
Other		Travel, Resource costs Operation preparation Construction management Insurance	12%	11-12%

Appendix D Summary of reference case inputs and results

Note: lifetime domestic supply percentages vary per site and per scenario, as they are calculated using site-specific parameters.

Incheon reference site

	Partnership scenario	Domestic scenario
Lifetime energy production (GWh P50)	52,678	41,726
Wind farm capacity factor	40	38
Total lifetime cost (real mil. €)	2.490,8	2.556,4
of which CAPEX - foreign	792,6	0,0
of which CAPEX - domestic	921,6	1.841,7
of which OPEX - domestic	776,6	714,7
% Lifetime domestic supply	68%	100%
LCOE (€/MWh)	75	91

South Jeolla

	Partnership scenario	Domestic scenario
Lifetime energy production (GWh P50)	60,705	48,109
Wind farm capacity factor	46	44
Total lifetime cost (real mil. €)	2.816,3	2.989,0
of which CAPEX - foreign	989,2	0,0
of which CAPEX - domestic	1.042,7	2.268,7
of which OPEX - domestic	784,3	720,4
% Lifetime domestic supply	65%	100%
LCOE (€/MWh)	75	95

Jeju Island

	Partnership scenario	Domestic scenario
Lifetime energy production (GWh P50)	52,516	41,595
Wind farm capacity factor	40	38
Total lifetime cost (real mil. €)	3.195,9	3.228,8
of which CAPEX - foreign	570,7	0,0
of which CAPEX - domestic	1.861,9	2.524,0
of which OPEX - domestic	763,2	704,9
% Lifetime domestic supply	82%	100%
LCOE (€/MWh)	101	120

Ulsan

	Partnership scenario	Domestic scenario
Lifetime energy production (GWh P50)	58,471	46,335
Wind farm capacity factor	44	43
Total lifetime cost (real mil. €)	3.417,4	3.459,2
of which CAPEX - foreign	570,7	0,0
of which CAPEX - domestic	2.083,5	2.754,4
of which OPEX - domestic	763,2	704,9
% Lifetime domestic supply	83%	100%
LCOE (€/MWh)	98	116

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