Bottlenecks in the offshore wind supply chain

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Executive summary – Bottlenecks offshore wind

The first part of the research focuses on identifying bottlenecks in the offshore wind supply chain in the North Sea. These bottlenecks were ìndentified during interviews with industry specialists at each step of the supply chain. At first the offshorew wind supply chain is defined.

- The economic bottlenecks are mainly related to the scarcity of resources in installation capacity, and labour shortages. These scarcities hinder multiple stakeholders to scale up their operations. These challenges combined with inflation and high CAPEX increase the financial risk making in more difficult to manage costs.
- The regulatory bottlenecks adress the lack of international system planning, which leads to inefficiencies in the supply chain planning. The lack of international operational planning is related to inefficiencies in the O&M phase due to inconsistent processes across different wind parks. Additionally, the efficiency and supply chain quality are insufficiently reflected in the tender criteria aiming to compare developers with simplified and measurable criteria. During the tender processes, there is limited transparency in the hardness of the bid commitments which increases the risk of cancelation.
- The Governance bottlenecks address the limited amount of information shared among stakeholders. Intransparency and competition lead to inefficiency in planning and innovation. Companies are hesitant to communicate interruptions, which prevents optimal planning and mutual learning. Companies reserve supply capacity; however, risk of cancellations remains even beyond failure in public tender, which increases the uncertainty of the available installation capacity. Especially for Chinese turbines, there is political uncertainty and lack of a joint vision/strategy on competition from non-EU countries.
- The technology bottlenecks address the concerns about the pace of demand-side mobilisation and sector integration which are expected to be too slow compared to planned offshore wind growth. Better alignment is essential for project developers for a healthy business model. Due to the fast increase in turbine sizes, the supply chain faces challenges. Shortages arise in the supply chain of components suitable for handling the scale. There is insufficient innovation and more complex operations and maintenance, current delays in maintenance are leading to additional costs.

Permits and Tenders → Project development → Design → Manufacturing → Logistics → Installation → Ops. & Maintenance → Decom missioning → Electricity users

Executive summary – masterplan

The first part of this study identifies key bottlenecks in the offshore wind supply chain, drawing on interviews with 13 sector experts: Most outlooks focus on the planned installation capacity until the year 2030. During this period, the is a steep increase planned in offshore wind capacity. To realise these plans, large scale investments in installations are required. Currently, however, these investments are lagging behind. A strong factor causing this lack of investments is the risk of a quick decline in planned installations beyond 2030. Such as decline in installations would imply the risk that long-term assets required to service the peak installation demand, like vessels and harbour capacity, become under-employed in the decades following the peak. A long-term outlook, with clear joint planning and standards would help alleviate this risk.

The second part of this study takes a first step towards the required long-term outlook, by combining many data sources into a single overview of planned installation capacity and required further installations to reach the 2050 targets. The analyses show several key findings:

There are large installation peaks in the North Sea in the years 2030-2031 and 2036-2037, especially caused by UK and German planned capacity. In the years between 2031-2036 and after 2036, yearly installations fall significantly. These findings provide empirical evidence and a quantification of the drop in demand for yearly installation capacity, as feared by investors currently.

Scaling up the supply of key resources and parts to service peak installation demand, such as installation vessels, will be challenging.

Both empirical findings call for a smoothing of planned yearly installations. A potential ways to achieve this, is through international collaboration, where countries avoid planning large instalments simultaneously. Indeed, many individual country planned installation peaks overlap.

Further research is required to explore possibilities for joint standards on wind turbine designs and components, and quantify their potential to reduce supply chain costs and uncertainty

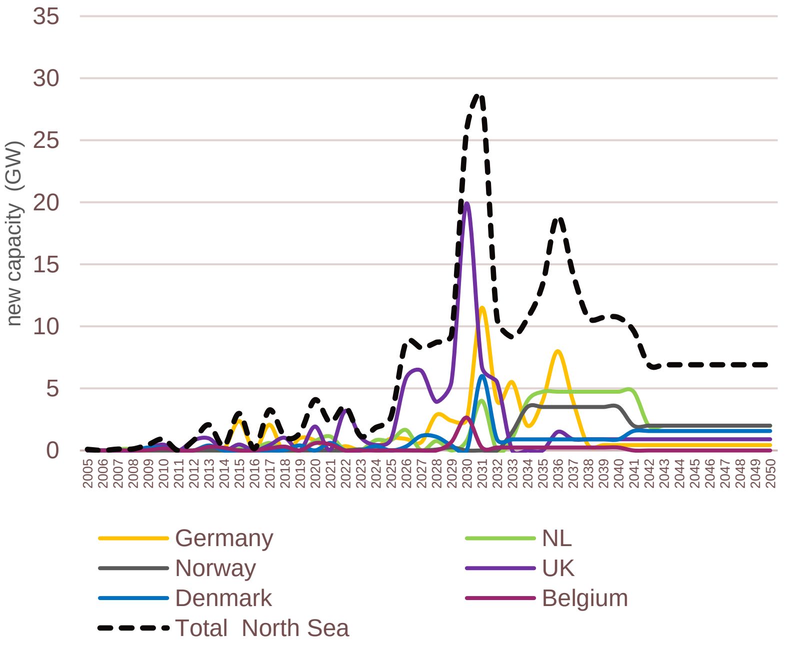


Figure 1: Annual new installation capacity for the North Sea

Source: Own calculations based on Esgian and manually collected data

Context of the study

This study is conducted during an internship project at Arcadis, which is part of the master program Energy Science at the University of Utrecht. Arcadis does have an extensive network of stakeholders within the offshore wind industry. This study is initiated by the ‘Offshore wind circle’, a group of managers from various companies and governments in the offshore wind supply chain. They have identified many uncertainties affecting the development of the supply chain. While companies do have extensive knowledge in their segment of the supply chain, a more comprehensive overview of the overall supply chain will be essential for seeking collaborative solutions.

PART 1: bottlenecks in supply chain

PART 2: Masterplan offshore wind

Problem definition

Challenges in the offshore wind supply chain

Despite the need for large investments in offshore wind to meet climate targets, their development is lagging. Since 2020, the business case for offshore wind is decreasing (Afry, 2024) and stakeholders experience negative financial results (Janipour, 2023a). Examples of current challenges hindering the rate in which offshore wind is developed, are uncertainty in electricity demand, increasing material prices due to inflation and increasing sizes of turbines (Janipour, 2023a).

The constantly increasing size of the turbines requires supply chain to adapt and components to be re-developed, increasing uncertainty. The new turbine sizes require constant changes in the design of, for example, the installation vessels. This can result in manufacturers being uncertain whether they have to buy a certain size of vessel, since a larger vessel may be required in a few years before reaching the economic payback. Therefore, manufacturers might be hesitant to making large investments. The development of larger platforms could stimulate the adoption of larger turbines, limiting technological optimization and economies of scale (Janipour, 2023a).

The challenges face by private offshore wind developers is reflected in a decreasing number of bids to offshore wind site tenders (Eneco, 2024). To reduce riskiness and increase the number of bids, new tenders will cut development locations into smaller areas (RVO, 2024b). While potentially reducing risk, larger cites could potentially lead to higher economic efficiency and technological advancements (NedZero, z.d.)

Societal relevance

Effective coordination between electricity supply and demand is necessary to avoid curtailment of electrification. Increasing certainty in the offshore wind sector, will enhance the reliability of affordable and green electricity. On the demand side, this reliability is crucial for industrial electricity users needing to invest in the electrification of their businesses. On the supply side, creating clarity around future electricity demand will provide greater stability for offshore wind developers, which potentially face challenges selling their electricity.

This research contributes to a comprehensive overview of all bottlenecks throughout the supply chain. The overview will facilitate better understanding of the challenges and therefore solution pathways seeking for more clarity in over the supply chain, helping an acceleration of the energy transition and reduction of green house gas emissions.

Research question and contribution

This first part of this study aims to provided a detailed understanding of the bottlenecks in the offshore wind supply chain for the North sea. While stakeholders have knowledge about the bottlenecks within their roles, a more holistic perspective is missing. A systematic and structured investigation of the bottlenecks is necessary to address the current and future bottlenecks in the supply chain.

The second part explores the planning of the new offshore wind installations beyond the scheduled tender planning. It seeks opportunities for enabling better coordination and to plan the roll out for offshore wind parks in the North Sea until 2050.

The following research question will be covered in the two parts of this research:

What are the key bottlenecks in the offshore wind energy supply chain, and how can planning for offshore wind parks until 2050 address these challenges?

Part 1 will cover the first two research questions:

- How is the offshore wind energy supply chain in the North Sea structured?
- What are the bottlenecks in the supply chain of offshore wind in the North Sea?

Part 2 will cover the next research question.

- What is the projected new annual installation capacity required to meet the 2050 offshore wind targets in the North Sea?

The first part covers the results of the 13 interviews conducted, with a variety of key stakeholders in the offshore wind industry. The interviews are conducted with persons, mostly in senior positions, who are directly involved in decision making. These up-to-date knowledge enables them to provide valuable insights of the current bottlenecks in the supply chain. In the context of a rapidly evolving market, these stakeholder interviews will provide relevant data that complements to the data from literature.

Primary research output this report, while the secondary research output is the dataset created used for part 2; the analyses of the planning of the North Sea up to 2050.

This dataset integrates multiple data sources, and is aggregated at the wind park level, including key dates, capacities and technologies used. Calculation are made to assess the average time between operation and installing the wind parks, and to evaluate the planning beyond the existing tender schedule. This data set can serve as a starting point for future research, enabling the exploration of alternative pathways aiming for the optimalization of the planning. This could help to limit the bottlenecks and enhance the feasibility of the offshore wind development.

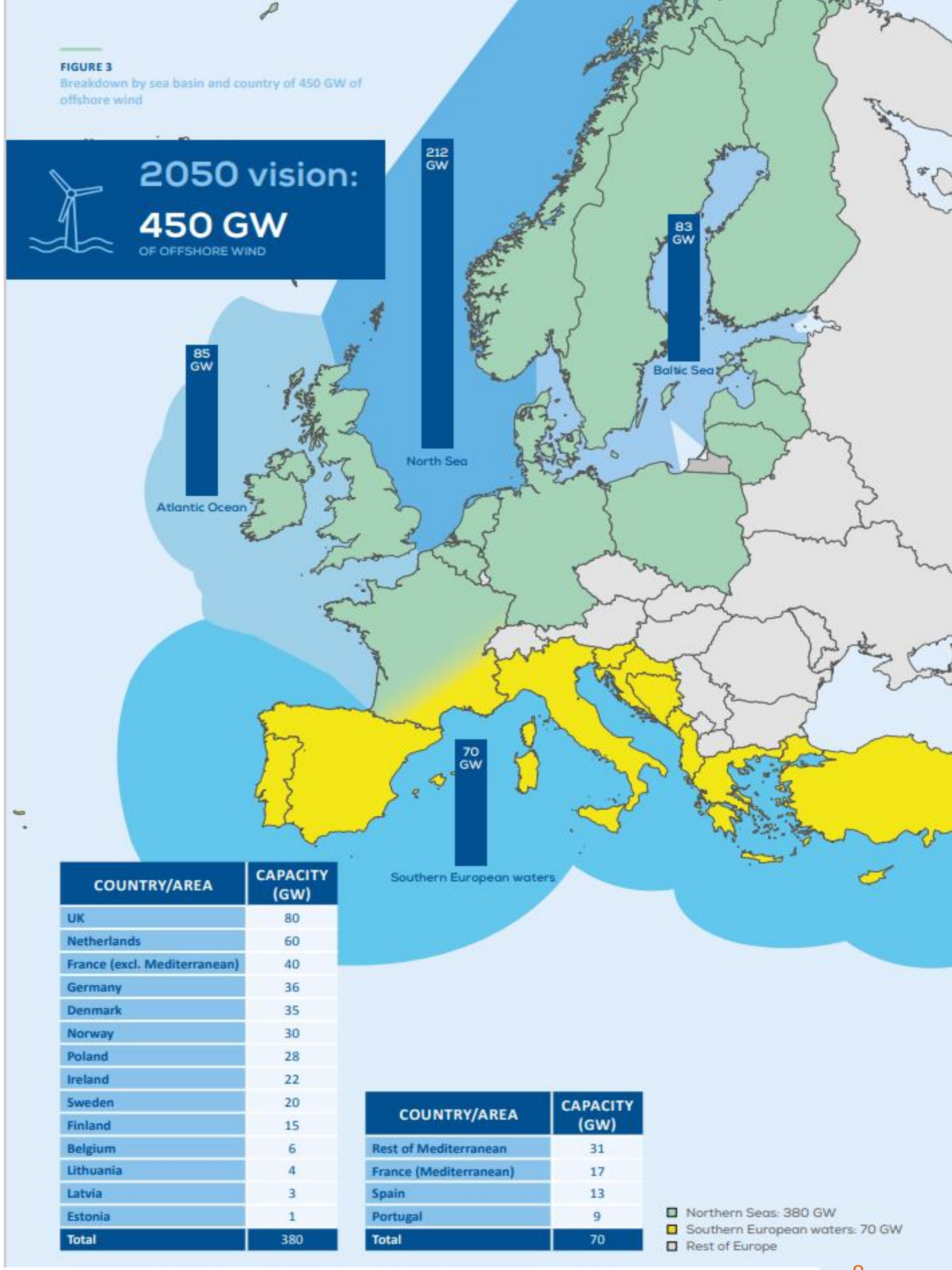
Background

The climate agreement in Paris seeks to mitigate climate change by reducing greenhouse gas emissions by 55% by 2030 and achieving climate neutrality by 2050 in Europe. To achieve these targets, the EU should switch from fossil fuels to climate neutral energy sources, mainly renewable energy sources. The Repower EU plan was developed to accelerate the share of renewable energy sources (European Commission, 2022).

Wind energy, and in particular offshore wind, is expected to contribute a significant share of the renewable energy supply. Offshore wind has advantages compared to onshore wind, because of the high and stable wind velocities resulting in higher energy yields compared to onshore wind energy (Díaz-Motta et al., 2023). Europe is a pioneer in the offshore wind, with the first offshore wind farm developed in Denmark in 1991, with 11 turbines combining a capacity of 5 MW (Ørsted. z.d.).

The size of turbines increased drastically over the years leading to higher capacities and reduced levelized costs of electricity (LCOE). In recent years, the turbines increased for 2 MW in 2005 to 15 MW in 2024, the turbine sizes are expected to increase the coming years (TNO, 2022). Other innovations for the foundations evolved such as floating wind turbines. This allows wind turbines to be placed further away from the coast, in deeper waters which enables more offshore wind resource potential (Janipour, 2023b).

The European target for offshore wind is 111 GW in 2030 and 317 in 2050. For the Netherlands, there is a national target for 21,5 GW in 2030 and 72 GW in 2050 (RVO, 2024a). The North Sea is a suitable place for the needed development of offshore wind parks, due to the high wind speeds, shallow waters and ports and (industrial) electricity users nearby (Rijksoverheid, z.d.) Currently, the largest capacities of offshore wind in the North Sea are installed in Germany, the Netherlands, UK and Denmark.



COUNTRY/AREA	CAPACITY (GW)
UK	80
Netherlands	60
France (excl. Mediterranean)	40
Germany	36
Denmark	35
Norway	30
Poland	28
Ireland	22
Sweden	20
Finland	15
Belgium	6
Lithuania	4
Latvia	3
Estonia	1
Total	380

COUNTRY/AREA	CAPACITY (GW)
Rest of Mediterranean	31
France (Mediterranean)	17
Spain	13
Portugal	9
Total	70

Figure 1: Vision of the European offshore wind targets . Source: WindEurope (2019)

Background

➢ **Terminology bottlenecks**

The term bottleneck is determined in literature as the imbalance in the supply chain where the supply chain capacity is smaller than the demand (Poulsen et al., 2017). This can be viewed differently among stakeholders depending on their perspective. For example, scarcity in an installation vessel can creates a bottleneck for the project developer but represents an opportunity for vessel fleet owner to charge a higher prices. While scarcity benefits exist, it hinder the broader goal of the roll out of offshore wind and therefore considered as a bottleneck for this research.

The offshore wind technology experiences a rapid growth in Asia, mainly in China. Many materials required for the turbines are produced in China, this allows China to have a shorter supply chain and allows them to produce at lower costs (European Commission, 2023).

China has become the world leader in the production of offshore wind, the coming 5 years their dominance is expected to increase. Chinese companies are increasingly expanding their market in Europe (TNO, 2024). Offshore wind parks are also evolving in other Asian countries, such as Taiwan, South Korea and Japan. There is also large potential for offshore wind in the USA, in recent years the government has set ambitious targets and is therefore expected to play a significant role in the energy transition. However, the offshore wind sector is still in its early phases (von Krauland et al., 2023).

Some countries are collaborating to expand offshore wind; France, Ireland, Luxembourg, Norway, UK Denmark, Germany, Belgium and the Netherlands. These countries will strive to turning the North sea into the 'Power Plant of Europe' (Ministerie van Algemene zaken, 2023). Next to the North Sea there are other European waters such as the Atlantic and the Baltic sea, which is used for offshore wind by European countries, such as Portugal, Poland and Italy.

According to the GWEC, there are arising several supply chain bottlenecks from 2026-2027 onwards. The potential bottlenecks studied are for key components for offshore wind among others; generators, blades, power converters, foundations. The bottlenecks are therefore important to analyse in depth, to make sure investments can be made on time to reduce the potential impact. (GWEC, 2024)

Related studies

Grey literature

Poulsen et al., (2017) studies the readiness of the supply chain for scaling up the offshore wind. In this article they differentiate the terms for Bottlenecks, constraints and barriers. The terms bottleneck is used to stress the imbalance in the supply chain where the supply chain capacity is smaller than the demand. The bottlenecks mentioned in this article for wind energy is the scarcity of sites, technologies for dealing intermittency, financial resources, government policies, subsidies and tariffs, human capital and skills, storage capacity and grid expansion and interconnection. Additionally the study of Tjaberings et al. (2022) provides an overview of the general life cycle stages, however does not include actors operating in these cycles.

The lack of private investment due large risks associated with large renewable energy projects is an example of transition failure. In this theory, pricing of the negative external effects is not sufficient in order to transition, since transition failure have more dynamic problems than market failure (Bolhuis, 2023). In this theory, transition management searches for a mutual goal, which the losses and benefits will be divided equally amongst different public and private parties. Transition failures, governmental intervention may be required when changes in behavior are hindered. The government should increase the certainty and insecurities to create a new market.

Due to this complexity, many researchers have labelled the sustainability issues as a wicked problem (Conradie, 2020). Wicked problems can be described by a set of characteristics (Rittel and Webber, 1974). Firstly, wicked problems are hard to define due to their complex and dynamic nature. In the same spirit, it is hard to say when the problem is definitely solved (no stopping rule). The solutions to a wicked problem cannot be classified as correct or false, but rather as good or bad depending on if they contribute in the direction of solving the problem or not. There is not a clear set of policy options from which to choose, but rather an infinite range of angles to the issue. Moreover, there is no opportunity for trial and error, making the problem path dependent on the solutions attempted (one-shot operation). Furthermore, a wicked problem can be seen as the result of another problem. The possibility to define different causes also results in different views on its solution. Still, the social planner has no room for mistakes and is considered liable for the consequences of its policies. These characteristics make each wicked problem unique.

Related studies - white papers

The scarcity of the port capacity in the North Sea region between 2030-2050 will be a significant bottleneck for scaling up the offshore wind (Royal Haskoning DHV. ,2023). The following challenges are identified; uncertainty in demand wind turbines, the non-viable business case, technical development risks, competition for space and incentive mismatch between actors in the sector.

Verboon et al (2023) studies the balance of the electricity supply and demand in variable scenario's up to 2050 in the Netherlands. These scenarios are based on the Integrated infrastructure planning (II3050) which differ from national to international oriented and high to low governmental leadership (Netbeheer Nederland, 2023). The various electricity demands in the scenario's is compared to national targets (21,5 GW in 2030 and 38-72 GW in 2050) and the mismatch is quantified.

The effect on the profitability of offshore wind in a low and high electrification scenario in the Netherlands is studied by Gonzalez-Aparicio et al., (2022). In the low electrification scenario, the business case for offshore wind is considered unprofitable.

The curtailment of offshore wind will rise from 0 % to 12 % in the low electrification scenario. In the high electrification scenario, electricity will be imported. The low-electrification scenario follows

KEV (Klimaat - en Energie verkenning 2021) (PBL, 2021), the high electrification scenario is found on the Routekaart Elektrificatie (RE) (Hers et al., 2021). The study of Aggreko (2024), highlight European countries are increasingly hindered by grid connectivity and lack of energy storage capacity causes delay in the construction for offshore wind farms. There is a roadmap for electrification of the industry and there is a roadmap for offshore wind with intermediate targets. However, there is a lack of coordination to meet these targets. A constantly changing environment is currently hindering long term investments. (RVO, 2024a) 'The New Dutch Offshore Wind Innovation Guide' mention several actors in the offshore wind sector in the Netherlands, however, is not applicable for the overall North sea. Afry studied the effect on variable developments of the business case for offshore wind. They provided several recommendations to decrease the LCOE for offshore wind (Afry, 2024). The European commission addresses several challenges in the offshore wind sector in the European wind act (European Commission, 2023).

Related studies: Private sectors studies

Private sector studies: Finally, there are private sector studies and initiatives dedicated to tackling the issue of lagging investments in offshore wind. For example, the North Sea Standard, a branch organization which seeks solutions for the constant changing turbine designs. They propose a maximum turbine size the coming 10 years (see Figure 2). On the other hand, research indicates there does not seem to be any limit on how big the wind turbines can become (TNO, 2022). In 2040, the research estimates the wind turbines can have a capacity of 27MW and blades around 145m long.

The study of Eneco (2024), evaluates tenders' policies in the Netherlands, they state the policies are currently insufficient. It provides several solutions in order to enhance competitiveness for offshore wind developers.

Rystad Energy (2021) provides an overview of different bottlenecks for different components such as turbines and foundations. However, several steps such as project development and decommissions are missing in this overview.

Figure 2: North Sea's Standard. Source: NedZero.

Method: Structure offshore wind supply chain

The aim of the first part of this study is to identify the bottlenecks in each step in the offshore wind supply chain. The initial step is clarifying the offshore wind supply chain for the North Sea. To map the supply chain a literature review is conducted, including variable sources, such as policy documents, white papers and scientific literature.

This process resulted in the collection of different maps describing the most important steps of the development of offshore wind. These maps were analyzed and combined into a list of the recurring themes identified by literature. The visualization of the supply chain increased the understanding of the interaction of the sector, which increased understanding of the overall context of the research

The completeness of the supply chain map was discussed during the first meeting with the Offshore Wind Circle. During this discussion, feedback was received and the map was adjusted. The next step involved the organization of the interviews, with the aim to conduct at least one interview for each step of the supply chain.

A list with relevant actors for each step in the supply chain was identified, which led to the creation of a supply chain map incorporating a lot of the relevant actors. At the start of the interviews, the draft version of the supply chain map was presented, along with the companies and institutions involved in the interview, the accuracy was validated. During the interviews, the operational details of each step in their supply chain were discussed.

Methodology: Structure offshore wind supply chain in literature

Before starting the interviews, a literature review was conducted to enhance the researchers' understanding of the supply chain and the bottlenecks identified by the literature. The literature review consists of various sources, such as policy documents, white papers and scientific literature, as covered by the related literature section above.

The offshore wind supply chain involves a complex structure of processes. There were several examples of the offshore wind supply chain found in literature which created a list with the supply chain for offshore wind Janipour (2023a), Tjaberings et al. (2022), Shafiee et al., (2016), D'Amico et al., (2017). They generally show the similar structures, which can be seen in the pictures. There are overlapping but also variations in the terminology used. These insights, are the foundation for creating the supply chain map which is used for the bottleneck analysis and starting point for the interviews.

Source: Tjaberings et al. (2022)

Source: Shafiee et al., (2016))

Source: Janipour (2023a)

Methodology: Conducting the interviews

To identify the current bottlenecks in the supply chain in the North Sea, 13 interviews were conducted with various stakeholders across the supply chain (see Table 1). The interviews were announced during a meeting with the ‘Offshore wind circle’, a discussion group with experts and managers from companies and institutions involved in all steps in the supply chain. During the meeting, the experts were presented with the research idea. After discussion, they contributed by providing access to their broad networks. To ensure a balanced representation, at most 2 interviewees per company were selected. The interviews were conducted with mostly Dutch representatives, working for a company or institution operating internationally.

To ensure confidentiality, Chatham House rules apply to the interviews, meaning it is allowed to use the information shared during the interviews, but not the identity of the interviewees.

At the start of the interview, the created supply chain map was presented including the key stakeholders. The interviewee confirmed in which stage(s) their company or institution is operational. Next, each interview started with the 5 general questions (See appendix X). They are asked to focus on the bottlenecks within their specific step in the supply chain. During the interviews, follow up questions were asked related to the general question to enhance deeper understanding of the topics. After covering the general questions, additional questions were asked about the bottlenecks found in the literature. This step allowed the stakeholders to validate whether these bottlenecks were relevant in their operation. By the end of the interview, the actors have to possibility to elaborate on other bottlenecks they see in other steps in the supply chain.

The interviews were recorded only after obtaining permission, when this was not the case, extensive notes were taken during the interview.

Tender Organizer	*Programme Manager Offshore Wind*
Project developer	Site Procurement Manager
	Bid Developer OFW
Project developer	Engineering Manager
	Senior Advisor Regulatory Affairs
Project developer	Managing Director Benelux Region
	Senior Lead Market Development
Installation Equipment Manufacturer	Product Manager
	Product Strategy Director
Turbine Manufacturer	Head Global Offshore Product Market
	Director Commerce Offshore
Transport and Installation Services	Head of Marine Projects
	Regional Manager Offshore Wind
Offshore Wind Project Constructor	Commercial Manager Offshore Energy
	Chief Investment Officer
Maritime Wind Energy Port	Commercial Manager
	European Development Manager
Maintenance and Operations Services	Managing Director
	Policy Advisor Energy
Chemicals Producer for Industry	Account Manager Energy
European research institute	Project officer- Innovation in Clean Energy Technologies

Table 1: the list of conducted interviews, categorized by sector and title of interviewees

Methodology: Processing interview findings

After transcribing the interviews, a summary of the answers was sent to the interviewees. The summary structured the interviews into 4 categories (see box) to structure the analysis.

Interviewees were asked to review the summary and respond whether their answers are interpreted correctly. In addition, they had the opportunity to add missing information if necessary. This summary covered the main takeaways from the interview and informed stakeholders how their input would be used in the research.

After validation and categorization of the individual interviews, the next step in the process was to combine the findings and seek for overlapping themes and bottlenecks. Each finding was labeled into one of the 4 categories using color coding. The findings were listed and assigned to the specific step in the supply chain. For each step of the supply chain, the findings were analyzed, and the overlapping results were identified and combined, and the frequency was recorded. This resulted in a comprehensive list of findings, the findings which were mentioned multiple times, were identified as the key bottlenecks.

The synthesized findings from the interviews are presented during a meeting with the 'Offshore wind circle' at the Offshore Energy Exhibition and Conference (OEEC) in November. This presentation provided a comprehensive overview of the three most important bottlenecks per category. This session facilitated a discussion in which the bottlenecks were evaluated, and potential solutions were discussed.

The results are structured into these 4 categories:

- **Regulatory:** Refers to policies such as the offshore wind targets and tender procedures.
- **Governance:** Refers to industry partnerships and collaborative structures.
- **Economic:** Refers to the market supply and demand and financial barriers for actors.
- **Technological:** Refers to innovation, infrastructure development, technological advancements.

This categorization is based on the PESTEL (Political, Economic, Social, Technological, Environmental, Legal) approach to industry analyses. For the purpose of the offshore wind supply chain analysis in this study, the framework is adapted to the needs of Arcadis: Regulatory combines legal and political decisions as these are often intertwined. Additionally, by setting environmental standards and carbon targets, the environmental dimension is often captured by regulation. Regulatory is a comprehensive term, capturing three dimensions. Governance is used instead of social factors, as the term social is broad and therefore difficult to apply for offshore wind industry dynamics. The term governance is more applicable for reflecting collaborative structures and stakeholder engagement. This term is more accurate in reflecting in the interactions between businesses, governments and other actors.

Interview results: Mapping the supply chain

The expanded and validated supply chain structure defined throughout the many expert interviews is presented below (Figure 3) .Some parties in the offshore wind supply chain operate in multiple steps and offered insights in multiple links in the supply chain. For each step in the supply chain, it is specified what type of actor in this step was represented in the interviews.

The key actors for **permits and tenders** processes are governments, although project developers also are involved in the decision making. The **design** phase is represented by the designers of the offshore wind turbines specifically. The **manufacturers** are represented by the stakeholders responsible making key components of the developing the offshore wind park, such as foundations and cranes. The l**ogistics** step refers to the ports and companies involved in transporting components of the offshore wind turbines.

The **installation** phase focuses on companies which, primarily operating with vessels, are involved in the installation of key components of the wind park, such as the foundations of the turbines.

Most actors are active in the **operation and maintenance** (O&M) phase. This phase is led by project developers who are the in charge of this process. Additionally, there are specialized O&M companies providing technical expertise for maintenance and handling interruptions. Other companies facilitating the O&M are also included.

The **decommissioning** phase refers to the breakdown of the offshore wind parks, at the end of their lifetime. While this step is included, there is a relatively small number of stakeholders currently involved in this step, due to the small number of turbines at the end of their lifecycle.

Initially, **the electricity users** were not included in the map. However, after discussion with the industry experts, the step was added to reflect the importance of industrial electrification for the rollout of offshore wind. This step is represented by the trade association of large-scale electricity users.

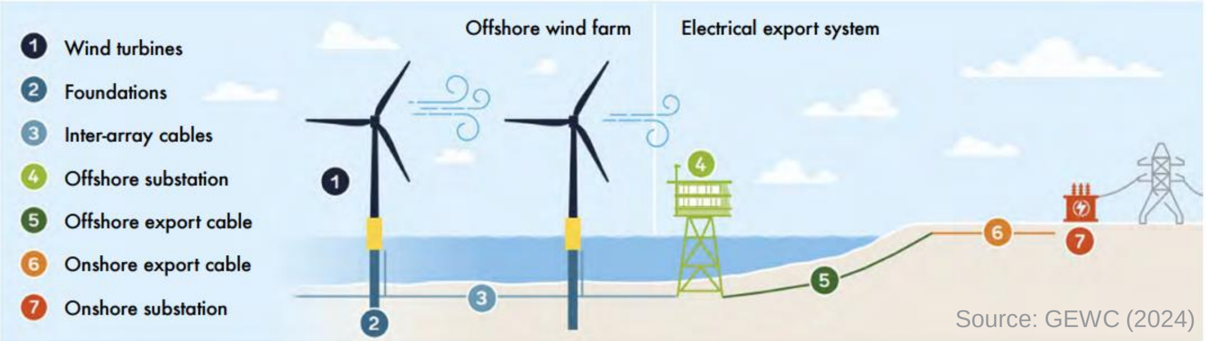
Defining the scope of the offshore wind supply chain

The supply chain of this research starts with permits and tenders. While the offshore and onshore cabling is an important part of the process of developing the offshore wind turbines, this aspect is not within the scope of the bottleneck analyses in this research.

This is partially due the regional differences of this process across the North Sea countries. In the Netherlands, project developers are responsible for the building the wind parks including the inter-array cables, foundations and wind turbines. While the

will cover the previous steps; the onshore and offshore export cables and substations (see figure). In contrast to, for example the UK, where project developers are in charge of the full organisation of the offshore wind grid.

Since the scope of this research is the North Sea, it aims to identify and align the overall critical supply chain bottlenecks, without delving into regional differences



Source: GEWC (2024)

Figure 3

Permits and Tenders → Project development → Design → Manufacturing → Logistics → Installation → Ops. & Maintenance → Decom missioning → Electricity users

Interview results: Regulatory bottlenecks 1

Efficiency and supply chain quality are insufficiently reflected in tender criteria:

- The current tender process is oriented towards innovation and delivery. Quality and efficiency of development and installation processes are left for the bidder to take care of. It is identified that limited transparency across the supply chain causes a situation with limited attention to quality of components and efficiency of production. Here, it would help to see to what extend tender criteria could enforce more focus on these factors, e.g. incentives for collaboration and long-term agreements with suppliers.

"Each country has its own tender criteria, which makes consistent planning difficult.“ – Turbine designer

Limited transparency in enforcing bid commitments:

- After the project developer wins the tender, there remains a possibility the project developer is unable to develop the wind farm. While there is a penalty fine for not finishing the project within the timeframe, some stakeholders argue this penalty is not high enough to guarantee the wind farm will be constructed. Additionally, people have noted intransparency in the enforcement of bid promises.

"The risk that parties cannot complete a project cannot be eliminated. Bank guarantees and annual fees helps” – Policy maker

Comments on directions for improvement

- Methods to solve these bottlenecks that are mentioned in interviews are focusing on a European approach, e.g. certification in O&M and more alignment in tender criteria between member states.
- The optimalization possibilities in supply chain planning needs to be investigated in more research, taking competition laws into account.

Interview results: Regulatory bottlenecks 2

- **Lack of international cooperation on operational planning:**

- the absence of international certification for maintenance hinders the transfer of workforce between different wind park operations. Additionally, the ecological measures implemented in Dutch wind farms differ from those in other European countries. This inconsistence can result in scenarios where wind farm may have to stop operating due to migrating birds, in the Dutch part of the North Sea, even though different requirements exist in other nearby wind farms. Currently, the tender criteria are designed to compare the project developers and aim for objectivity and concrete measurable criteria. While they strive for simplicity, the quality of the project developer is not adequately considered.

- **Lack of international cooperation on system planning:**

- Tender criteria differ across countries; this inconsistency means that different characteristics are prioritized. Because the companies operate in multiple countries, this leads to a challenge in determining a clear direction. It can be argued that these differences are beneficial to create distinctive capabilities for bidders. However, it can also contribute to more uncertainty for the supply chain and increase the cost of tender applications, as varying criteria across tenders lowers returns to scale in tender applications. When offshore wind will be exported to other European countries, stakeholders argue that the infrastructural costs paid by the government through TenneT, should be shared among receiving countries. However, there is currently no mechanism for distributing the costs.

"The migration patterns of birds are often based on data and models that are not always accurate. This could result in a wind farm being shut down unnecessarily.“ – Project developer

"The network tariffs in the Netherlands are too high compared to other countries. This disadvantages the competitive position of our end customers.“ – Project developer

Interview results: Economic bottlenecks

Labor shortages and lack of future workforce planning:

- Many companies operating in the offshore wind business are currently experiencing difficulties with finding workforce. This is mostly in issue for the logistics, installation and operation and maintenance phase. Consequently, some labour-intensive projects might be delayed.

Scarcity in installation resources:

- There is a shortage of installation capacity, particularly due to a limited availability of installation vessels. Additionally, for the use of heavy lift vessels which are currently used to transport the turbines, are in high demand and face competition from the oil and gas industry.

Cost volatility impacting financing:

- Inflation and rapid changing turbine models, have driven up the costs of a wind park. Project developers are delaying final investment decisions. There is uncertainty surrounding market commitment. The uncertainty about the pace of the electrification of the industry is currently resulting in an undetermined electricity price, and this is currently not secured by regulations such as contract for difference (CfD).

- External pressures, like the rapid expansion of the Chinese turbines manufacturers, are intensifying competition for European turbine manufacturers. Chinese manufacturers benefit from an uneven playing field, as they are subsidized by the Chinese government.

- The existing tender system enables negative bidding. Some companies argue this adds little value to the process and may lead to increased overall costs for the wind park. With this system, the project developer with the most optimistic market projections is more likely to win the tender. To fulfill these projections, the project put pressure on the supply chain, which can potentially result in unrealistic demands

"There is a significant shortage of people who can do this work, especially in maintenance and operational services." – O&M specialist

"You can't really control the risk; it is determined by external factors. Think of the demand for electricity—if the EU implements poor policies and industries disappear, as is happening in the Netherlands, then that becomes the least controllable risk." – Project developer

Interview results: Governance bottlenecks

- **Intransparency and competition leads to inefficiency in planning and innovation:**

- The limited communication across the supply chain is currently leading to inefficiencies in the market. For example, specific components produced in China, are often delayed, which result in logistical challenges in the following steps of the supply chain. When there are technical issues or logistical delays, companies are hesitant to communicate this, which may result in inefficient planning. O&M companies, experience late request for scheduled operation, which can also lead to inefficient planning and less available .

"In the Netherlands and Germany, projects are often won through speculative bids. This makes scaling up more difficult, as it is not certain that these projects will be built."– Turbine designer

- **Companies reserve supply capacity; risk of cancellations even beyond failure in public tender:**

Project developers are investigating manufacturing companies which have the capacity to build the wind parks. While Agreements are made, final investments decision are often delayed. As a result, turbine manufacturers must **reserve production capacity** for the project developer, while having the risk the project might be cancelled. There is political uncertainty regarding the extent to which wind park targets will be met. European policymakers may shift their position to offshore wind due to the constant changing market conditions. Similarly, in the United States, the expansion of wind park is highly influenced by the political party in power.

- **Political uncertainty and lack of a joint vision/strategy on competition from non-EU countries:**

There is no clear vision on the competition of non-European countries, particularly related to the rapid expanding Chinese wind turbines production. Companies have various perspectives on the future role of these Chinese wind turbines. Some argue that importing Chinese wind turbines is essential to accelerate the energy transition, while others are hesitant and emphasize potential quality issues and cyber security risks. "If Europe excludes Chinese turbines, you have to accept that the rollout pace of offshore wind will slow down."

"If Europe excludes Chinese turbines, you have to accept that the rollout pace of offshore wind will slow down." – Project developer

Interview results: Technological bottlenecks

- **Pace of demand-side mobilization and sector integration too slow compared to planned Offshore Wind growth**

- This reflects the concerns of project developers about the pace of electrification. The industry especially, is currently lagging in its electrification efforts. The growth of the offshore wind capacity may lead to an overcapacity of electricity and therefore lower electricity prices which negatively impacts the business case of offshore wind parks.

"Maintenance is becoming increasingly complex as turbines grow larger. More specialized knowledge is required.“ – Turbine designer.

- **Supply chain implications of larger turbines:**

Over the years, the turbines increased in capacity, along with many components of the supply chain, leading to various challenges. Continuous design changes require time and financial investments. These investments required for new designs and innovation results in rapid depreciation for existing technologies. With bigger turbines, new technological challenges arise. For example, vessels must scale up to transport or install the new turbine. While installation vessels capacity can sometimes increase by replacing a larger crane, there are technical limitations.

Shortages arise in the supply chain of components suitable for handling the scale, such as hammers and foundations. Additionally, shipyards are fully booked due to oil and gas market. There are concerns about the limited production capacity of the EU-turbine producers. Larger turbines face challenges due to the increased wake effects which can reduce the efficiency of the wind turbines.

- **Insufficient innovation and more complex operations and maintenance:**

There are criteria for in tenders for innovation, such as a measuring tool for migrating birds which could potentially be hit by the blades of the turbine. These innovations are in development and not the accuracy is not sufficient.

"For each project, we create a saddle specifically tailored to fit. If there were more standardization in the dimensions of foundations, we could save a lot of costs.“

Conclusion interviews

In short, the interviews have brought the following conclusions on bottlenecks in the offshore wind supply chain in the North Sea:

- The economic bottlenecks are mainly related to the scarcity of resources in installation capacity, and labour shortages. These scarcities hinder multiple stakeholders to scale up their operations. These challenges combined with inflation and high CAPEX increase the financial risk making in more difficult to manage costs.
- The regulatory bottlenecks address the lack of international system planning, which leads to inefficiencies in the supply chain planning. The lack of international operational planning is related to inefficiencies in the O&M phase due to inconsistent processes across different wind parks. Additionally, the efficiency and supply chain quality are insufficiently reflected in the tender criteria aiming to compare developers with simplified and measurable criteria. During the tender processes, there is limited transparency in the hardness of the bid commitments which increases the risk of cancelation.
- The Governance bottlenecks address the limited amount of information shared among stakeholders. Intransparency and competition lead to inefficiency in planning and innovation. Companies are hesitant to communicate interruptions, which prevents optimal planning and mutual learning. Companies reserve supply capacity; however, risk of cancellations remains even beyond failure in public tender, which increases the uncertainty of the available installation capacity. Especially for Chinese turbines, there is political uncertainty and lack of a joint vision/strategy on competition from non-EU countries.
- The technology bottlenecks address the concerns about the pace of demand-side mobilisation and sector integration which are expected to be too slow compared to planned offshore wind growth. Better alignment is essential for project developers for a healthy business model. Due to the fast increase in turbine sizes, the supply chain faces challenges. Shortages arise in the supply chain of components suitable for handling the scale. There is insufficient innovation and more complex operations and maintenance, current delays in maintenance are leading to additional costs.

This list of recurring themes discussed.

1. System and operational planning
2. Reflectivity of tender criteria
3. Transparency of commitments in bids
4. Labor shortages
5. Installation capacity
6. Cost volatility and business case certainty
7. Joint planning and innovation agenda
8. Certainty of project feasibility
9. Vision competition with China
10. Electricity demand integration
11. Larger turbine/North Seas Standard
12. Operational implications

Discussion interview results by supply chain link

Permits and tenders; most of the bottlenecks are considered as regulatory. The variable tender criteria across countries, which leads to a challenge in determining a clear direction. Additionally, the negative bidding processes leading too optimistic market projections and risk for cancelation

Project developers: Most bottlenecks are determined as economic and relate to the increasing risk for the business case. Which is in line with the findings of afry (2024), however there is an increasing concern identified about the slow pace of the electrification of the industry and therefore limited electricity demand.

Design: The technical implications with the increase in capacity of turbines were considered as key bottlenecks for turbine designers and manufacturers. Additionally, the reservation of capacity and potential risk of cancellation of a project even beyond tender, increases the uncertainty for the demand for turbines.

Manufacturers are facing technical implications due to larger turbines. Additionally, governance bottlenecks are increasing the risk of scaling up capacities. External pressures, like the rapid expansion of the Chinese turbines manufacturers, are intensifying competition for European turbine manufacturers.

Logistics are facing implications of larger turbines, long lead times and logistical delays due to limited communication. They are facing challenges related to the competition with the oil and gas market, and shortage of skilled labor. Furthermore, increasing port capacity requires a long time, greater consistency and long-term planning for offshore wind is required to ensure the viability.

Installation: are mainly dealing with technological and economical bottlenecks. Installation scarcity related to the continuous demand for new equipment due to the changing turbine designs. This involves high investments and long lead times which is challenging with the rapid evolving market conditions.

Operation and maintenance; Most of the bottlenecks are related to technical and regulatory, such as uncertainty in dealing with f.e. congestion issues and bird migration. Additionally, there is a scarcity of skilled workforce, which is partially due to the lack of international certification for workforce.

The electricity users face economic bottlenecks due to high electricity prices and risk management, especially for the Netherlands. The governance bottlenecks refer to the lack of a system wide approach, the company’s involvement during tender processes is limited.

Proposed solutions

The interviewees proposed several solutions to adress the bottlenecks. For examples, aligning tender criteria across the member states. Next to this, the industry is aiming for improved planning in supply chain optimization, in which the competition laws are respected. Next, there should be more transparency in the trends and aligments of the governmental goals, offshore wind supply chain and the needs of the electricity consumers.

Evaluating these solutions, it becomes clear overaching coordination is required. Therefore, enhanced is required for long term supply chain effiiency. It needs to be further investigated to assess the impact of planning on the steps and actors in the supply chain.

Limitations

There are limitations with the method used during the interviesws. While a diverse group of stakeholder were interviewed, the number of bottlenecks indentified varied between interviews. This does not accuratly reflect the amount of bottleneck in each step of the supply. This could also be reflect the differences in the interview process and the opportunity to ask follow up questions. A learning curve was experiences with both understanding the topic and conducting the interviews, which improved the ability to gather data over time. This may have resulted in an overrepresentation of bottlenecks in certain supply chain steps.

The categorization of the bottlenecks into regulatory, governace, economical and technical is a simplified method. For some of the bottlenecks the categorization was not straigtfoward and dependent on the perspecitve. For further research it is valuable to to identify the root causes of the bottlenecks which will be more effective in seeking solutions for the bottlenecks.

When identifying key bottlenecks, a more accurate approach would be to list the identified bottlenecks and create a survey in which interviewees rate the short and long term importance of the bottlenecks.

PART 2: Master plan offshore wind

Introduction: Optimize long term supply chain efficiency

The interviews highlight need for improved planning to achieve long term supply chain efficiency. Interviewees stress the importance of transparent and internationally coordinated strategies for the future rollout of offshore wind. Long term planning is essential due to the high investments required and rising uncertainty about the project viability. Additionally, the industry is facing bottleneck such as long lead times and product scarcity driven by increasing turbine sizes, leading to resources and facilities becoming outdated more quickly than anticipated. Therefore, it is crucial to optimize the utilization of both existing and new installation capacities.

Part 2 covers the initial attempt to clarify the long-term planning by creating an outlook for the new annual installed capacity up to 2050. This calculations were based on the scheduled tenders and government targets for the North Sea countries. Governments set ambitious targets to achieve the Paris agreement and develop a clean and affordable energy system. These targets indicate a significant growth for the offshore wind industry in the coming years. This study gathers these targets and translates them in to the required annual new installations for each individual countries and for the North sea as a whole.

Related studies

- The following studies are analyzing the planning for the offshore wind in Europe.

WindEurope created an overview of the new annual installations and the total capacity for onshore wind in 2030. (WindEurope, 2024b)

The global wind energy council (GWEC): published annual reports about the global wind trends, including a Global Offshore Market Outlook to 2033. In which they describe the annual installation for Europe, China, Asia Pacific, North America and other. For all the individual countries of Europe, the new offshore wind installations are plotted a swell. This shows an increase in offshore wind installations, for 2031-2032 the new offshore wind installations are similar. The new offshore wind installation are compared to the f.e. planned fixed bottom foundation installation capacity worldwide.

The NSEC, created a tender planning for all NSEC countries. It describes the scheduled wind parks, with their expected tender and operational date.

- There is increasing attention in the acceleration of the offshore wind projects.

The time between the tender and the commissioning of the projects depends on country specific regulations. The average commissioning time of offshore wind projects in OECD countries is 5,4 years (Gumber et al.,2024). This study considers account 105 projects between 2005-2022.

The wind power action plan (2023) is acknowledging the difficulties of the industry and calls for immediate action which should optimize the tender process and the fast development of offshore wind.

To reach the 107 GW, European offshore wind targets in 2030, 11,4 GW should be the annual installation capacity looking at the EU's member state targets. This capacity is not with the estimated capacity from Bloomberg, which is estimates a capacity of 70,5 GW in 2030 for the EU, which results in a installation gap as shown in the table below

Table 1: Gap between the forecast installation and the sum of the EU member states' offshore wind energy national targets by 2030

	EU offshore wind capacity by 2030	Average annual capacity installation (2023-2030)
Sum of national offshore wind energy targets of EU member states	107 GW*	11.4 GW (required)
BloombergNEF forecast**	70.5 GW	6.8 GW
Estimated gap	36.5 GW	4.6 GW

*Note: All units are in rounded GW **Note: BloombergNEF data plus Ørsted's recently announced 1.5 GW Swedish project
Source: BloombergNEF, Rabobank 2023

Table 1: Source: Janipour, 2023c. forecast offshore wind capacity EU member states

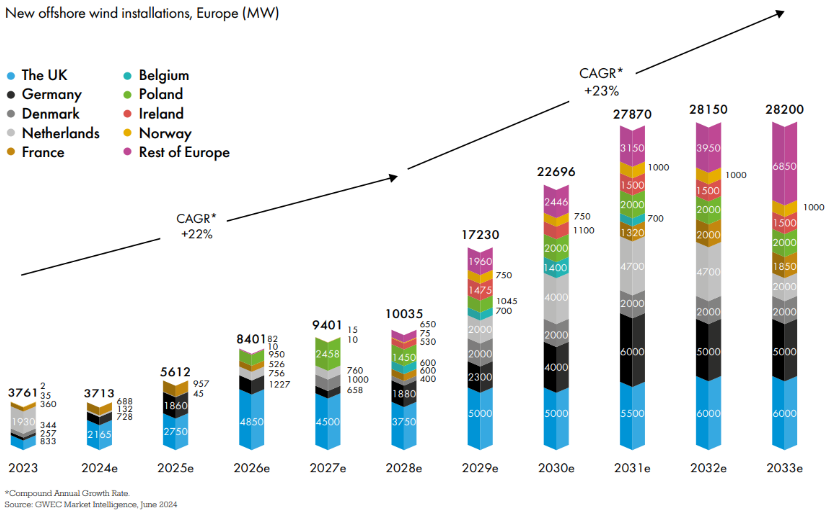


Figure X: Source: GWEC offshore wind capacity outlook EU

Related studies: Beyond the storm

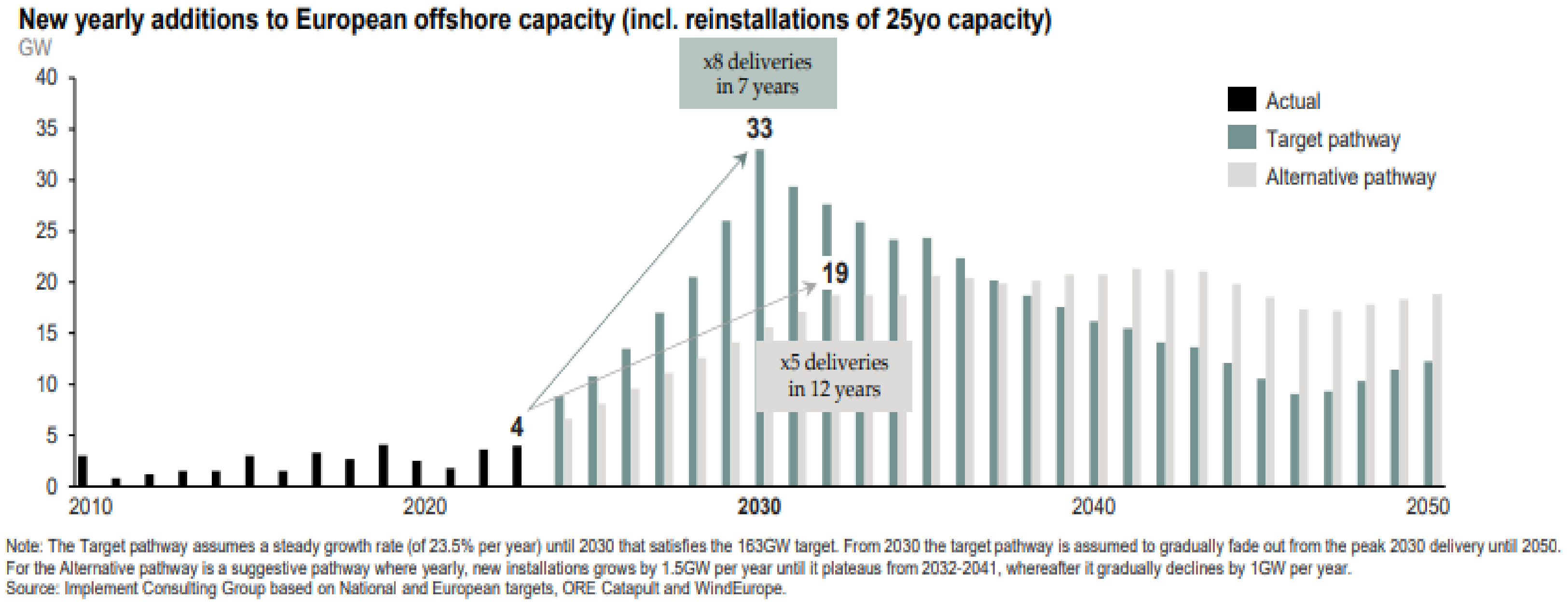


Figure 4: New yearly additions EU. Source Implement consulting group (2024). Beyond the Storm

The study Beyond the Storm (Implement, november 2024) highlights the projected increase in annual capacity until 2030, followed by a decrease in installed capacity around 2040 and 2050 (Figure 4). It emphasizes that it is unrealistic to meet the political targets set by 2030 and regulatory frameworks need a more consistent and long term perspective approach.

As shown in the figure above, there is a peak in annual installations around 2030. They note that the accelerating the supply chain capacity until 2030 may result in overcapacity towards 2050.The study proposes they for an alternative pathway in which the investor confidence may increase due to enhanced collaboration and long term planning to prepare the supply chain.

The alternative pathway is suggested to align the implementation of EU capacity and to reach the targets more effectively by managing the supply and demand and the increasing the overall market predictability.

While “Beyond the Storm offers valuable insights, the masterplan complements the study by providing additional distinctions which is a useful foundation for further research.

Specifically this research:

- Differentiates between individual countries, which provides a detailed understanding of each contribution to the total capacity required.
- Separates the capacity specifically for the North Sea and other,
- Distinguishes between the fixed and floating foundations, which is useful for technology specific resources availability.

These distinction can provide a framework for addressing follow up questions such as:

- How to coordinate a joint capacity planning across these countries
- Which projects should be prioritized to maximize the resource capacity?
- How does the availability of the resource capacity align to the target pathway and the alternate pathway?

Scope

ARCADIS

1. The **North Seas Energy Cooperation +UK**

   NSEC is an intergovernmental forum which is focuses on the development of offshore wind expansion in the North Seas, which include the Irish and Celtic Seas as well. The UK left the NSEC because of the Brexit in 2020. For a better understanding of the scheduled tenders, and the installed capacity required for the North Sea, the UK is also considered in this research. The UK does have a large share of the offshore wind capacity and the capacity is expected to increase up to 2050.

2. **Floating:**

   This research includes wind parks with floating foundations. However, there is a distinction made between the floating wind parks and the fixed wind parks, to enable a better analyses of the number of foundations required and the installation resources specific to each technology.

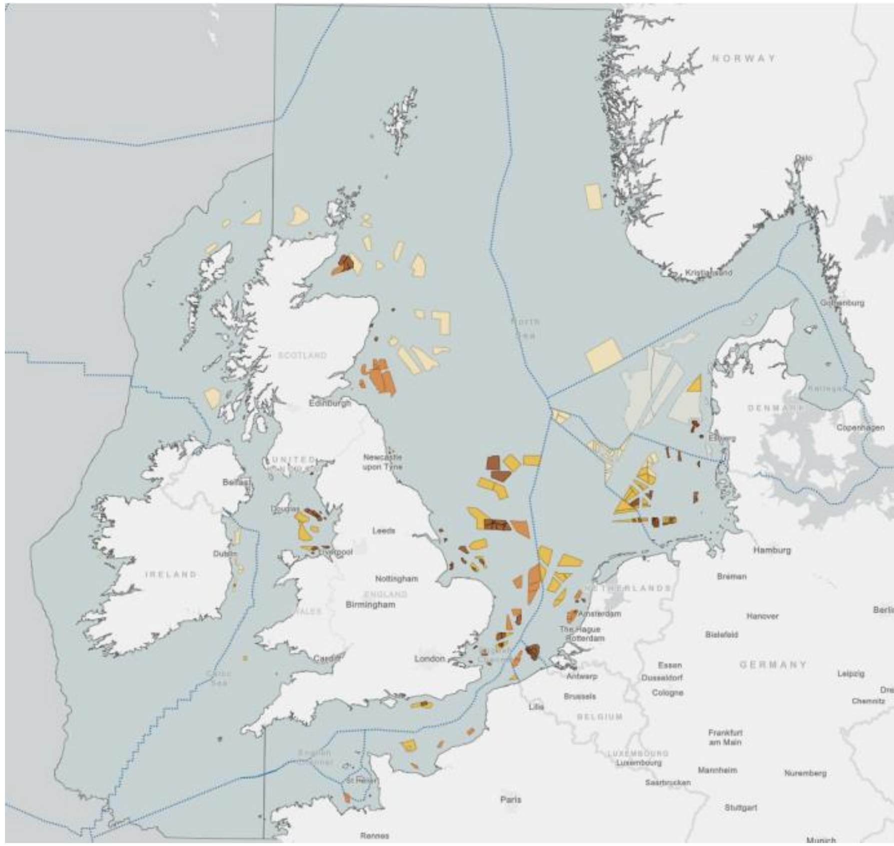
3. **The North Sea:**

   This research focuses specifically on the North Sea. Among the countries of the NSEC +UK, the offshore wind parks in Ireland and France are not located in the North Sea and for UK and Germany they are partially located in the North Sea. In the appendix the overall projections of the NSEC+UK countries are included to provide a broader context. In this way, the results of the North Sea can be validated with the overall projection, to check whether the trends for the North Sea equal the overall trends. Additionally, it allows for a comparison with the installation resource capacity across Europe.

   Evaluating the specific needs for the North Sea is relevant because of the following reasons.

   - Analyzing the resource installation capacity with the targets. This is necessary to investigate the resources needed for the North Sea specific projects and the countries targets.
   - North Sea specific targets are required to evaluate the infrastructure and logistics needed for the installation of the wind parks. This for example related to the growing concern for the availability of marshalling ports.
   - Specifying the timing of the parks specifically in the North Sea is relevant to link to special planning, marine life and other activities in the North sea
   - Estimate the scale of grid infrastructure and interconnections to North Sea countries

North Seas Energy Cooperation



Current and scheduled offshore wind park. Source: Royal Haskoning (2022)

Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and the European Commission are currently members of the North Seas Energy Cooperation,

Methodology masterplan

In the methodology some overall assumptions are described. More information about country specific assumptions for the calculations are listed in the appendix.

To project the annual installation capacity up to 2050, historical data and future are utilized. The steps will be discussed below.

- **Targets:** For all the NSEC countries + UK the offshore wind targets were identified. These targets were found in European and national policy documents. Targets for each country were found, most of the countries have an overall offshore wind target for 2030, 2040 and 2050. In these targets, there is no specific target for location or floating/fixed, it refers to all the capacity of the countries offshore wind parks.

- **Custom data set:** To analyze the existing and scheduled offshore wind park, a custom-made data set of was Esgian. Esgian is a wind analytics platform, which strives to provide an up-to-date dataset with the current market development. The dataset included project data for all existing and scheduled wind parks NSEC countries +UK, it covers a wide variety of information. The following data was used for this analysis; Name offshore wind park, Capacity, Number of turbines, Foundation installation date, Operation date, Fixed or floating.

- **Data cleaning:** The suspended and decommissioned parks were deleted from the dataset. This would lead to an inaccuracy in the total amount of installed capacity of each country. Separate data sets were created for each country, for each wind park of the country, the year of the operation was derived. For each year between 2005 and 2050, the total operation capacity was summed up. The installed capacity was checked with the data sources used in method 1 to enhance accuracy. When a year is not determined (most of the time for future projects) the capacity is not considered in the scheduled tenders.

- **Determine the average time between the operation date and lease round date and foundation installation date for planning.**

At first the average time between foundation installation operation was calculated with the available data in the Esgian data set

To determine the average time between the Lease round award date and the operation date, this process was more complex. The Esgian data source included a list with tenders including the names of the Lease Round Name and the Lease area name. Including the "Lease Round Open Date, lease Round Close Date and the lease Round Award Date. The lease round name is an overlapping name, which refers to the all the wind parks with equal lease round dates. For the lease round areas, the names of the specific wind park is mentioned, which can be equal to the lease round date. But sometimes there are more areas tendered in one lease round.

To link the operational date with the lease round award date, challenges arise due to inconsistent naming for the project data and the tender data. All the names of the lease areas had to be compared to the names of the projects data. After resolving most of the inconsistencies, the difference in lease award date and operational date was calculated.

Methodology masterplan

- **Validation of the data:** To ensure the reliability of the tenders, the scheduled wind parks were compared to the NSEC tender planning. The NSEC planning provides a list of the scheduled tenders and the expected operation date of all the NSEC countries (UK not included). See Table 2 for an example of the data. Some of the scheduled wind parks in the NSEC tender planning were missing in the Esgian data and manually added. Including the additional details; the lease award date, operational date, capacities and technology (floating/fixed), described in the NSEC planning. In case the time between the operational date and the lease round award date appeared unrealistic, due to a short or long duration the data was corrected with additional project data coming from governmental and project developer websites.

- **Create an overview of all the operational and scheduled wind parks:** After the validation of the data, there is a final list of the wind park data of the operational and scheduled wind parks, the annual capacity of new installations each year is calculated. Adding all the annual additions results into the overall installed capacity.

- **Post tender planning:** For the years beyond the tender planning, a different method is used to determine the annual installation capacity. The ending year of the tender planning differences per country, for Germany the last scheduled wind parks start operating in 2037, for Belgium this is 2030. For each country, the annual new installation estimation starts when the tender planning ends.

  The difference in installed capacity beyond the tender planning and the next target will be distributed over the remaining years. For example, when a country has a target for 2040 and the tender planning ends in 2034, the difference in capacity will be spread equally over the six years. After reaching the 2040 target, the remaining capacity to meet the 2050 target is spread evenly over ten years. To allow for better interpretation of the results, plots are created in which the annual fluctuations and increase in capacity can be clearly observed. After completing the steps for all countries, the total capacity outlook is created. This is the sum of all the new annual capacity over the years, and the total installed capacity, for the NSEC+UK.

Project	Country	Project status	Project type	Capacity (MW)	Number of turbines	Operation date
Borssele I&II	Netherlands	Operational	Fixed foundation	752	94	01/11/2020
Borssele III&IV	Netherlands	Operational	Fixed foundation	731	77	01/02/2021
Borssele V Test Site	Netherlands	Operational	Fixed foundation	19	2	01/02/2021
Egmond aan Zee	Netherlands	Operational	Fixed foundation	108	36	01/01/2007

Table 2: example of a fraction of the data from Esgian - NL

Methodology

- **Filter results for in dept analyses:** After completing the steps for all the wind parks of the NSEC + UK, the data is filtered on technology and location.

  Fixed and Floating: The first filter is the separation of wind parks with fixed and floating foundations. This technology differs, and this provides information on the resources required to install the wind park. This distinction allows for a better understanding to evaluate the number of monopiles required in the coming years. The share of floating and fixed turbines for the North Sea were identified for the scheduled tenders. The number of floating wind parks is relatively small, there is no projection for the share of floating wind parks beyond the tender planning due to a lack of sufficient data.

  North Sea: Since the scope of the research is the North Sea, we excluded Ireland and France from the analyses. Additionally, the locations for the UK and Germany had to be specified since they have wind parks located in the North Sea and other seas. Since the dataset lacked locational data, additional data was required. For the UK, the location of 120 wind parks were determined by manual google maps searches, the Esgian offshore wind map, or other websites of project developers. For Germany, the annual capacities were found in the ‘Status of Offshore Wind Energy Development in Germany’ (2024).

  In order to determine the annual new installations after the tender planning the 2040 and 2050 target should be adjusted. When remaining the countries target, it would incorrectly assume that all the wind parks after the tender planning will be located at the North Sea. Therefore, the share of installed and scheduled wind parks located at the North Sea is calculated for the UK and for Germany. A new country target is calculated assuming the same share of wind parks will be located in the North Sea beyond the tender planning. A new total capacity outlook was created, only including the wind parks in the North Sea.

Process description: Previous method.

Initially, data from the Wind Europe report on the expected installed capacity in 2024- 2030 of all European countries was used. To determine the installed capacity untill 2024, data from statista and governments websites.

For the period beyond 2030, the annual installation to meet the targets in 2040 and 2050 for each country were calculated manually.

During the process, the following challenges in the method.

It was difficult to determine which tenders described by the NSEC tenderplanning were already taken into account in the expected installed capacity iin 2030 (windeurope, 2024b).

There was no distinction for the location (North Sea or other) and the technology used (fixed or floating) and missing data for UK.

The Netherlands

Tender planning untill	2033
Location	North Sea
Installed capacity (GW)	
2024	4,6
2032	21,5
2040	50
2050	70
Average time between operation and:	
foundation installation	1,5 years
lease award date	4,9 years
Type	Fixed

The Netherlands is expected to install a large amount of offshore wind turbines, when reaching the targets of 2050. After the 2032 target, the tender planning is yet to be developed.

In Figure 5, there is a peak observed around 2030 in the total installation capacity. In order to reach the target in 2040, there is calculated that the annual installation should increase to 4,5 GW/year. This is equal to the current installed capacity. After 2040, the expected annual nstallation will drop the 1,7 GW.

The Netherlands has a relatively short average time between operation and lease award date.This is

Country specific challenges:

- The concerns about the pace of electrification of the industry and therefore the demand integration of the increasing amoung of electricity generated by offshore wind parks.
- The congested electricity system may cause delays in system integration and high electricity system costs which is a risk of the business case of offshore wind parks.

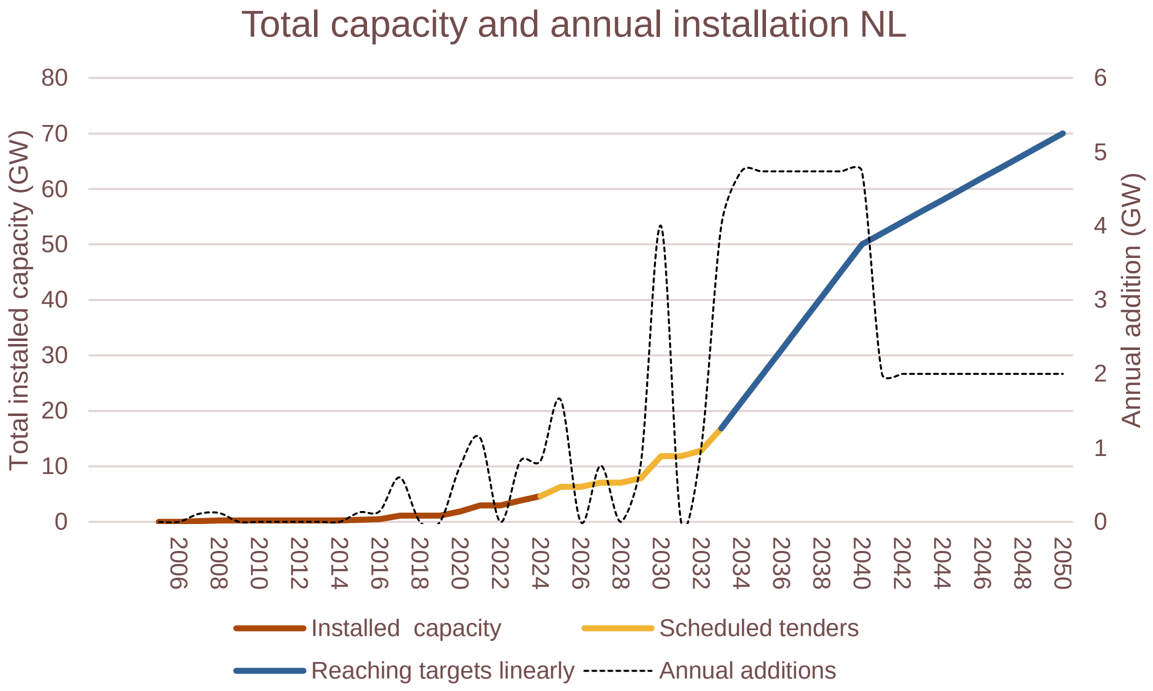


Figure 5; Source: Own calculations based on Esgian and manually collected data

Germany

The latest tenders of Germany are expected to be operational in 2037, with 94% in the North Sea and 6% in the Baltic sea, all with fixed foundations (Figure 6).

- According the tender planning, 11,5 GW of newly built capacity will start operating in 2031.
- There is another peak expected around 2036. By 2037, the 2040 target of 60GW, is expected to be already operational, after which the annual installation capacity is expected to decline significantly.
- The time between operation and foundation installation is average comparing the other EU countries. The time between lease award date and operation is relatively fast.
- Germany faces geograpical challenges and have to risk to have higher wake effects.

Tender planning untill	2037
Location	North Sea & Baltic Sea
Installed capacity (GW)	
2024	8,7
2030	24,6
2040	60
2050	66
Average time between operation and:	
foundation installation	1,8 years
lease award date	6,4 years
Type	Fixed

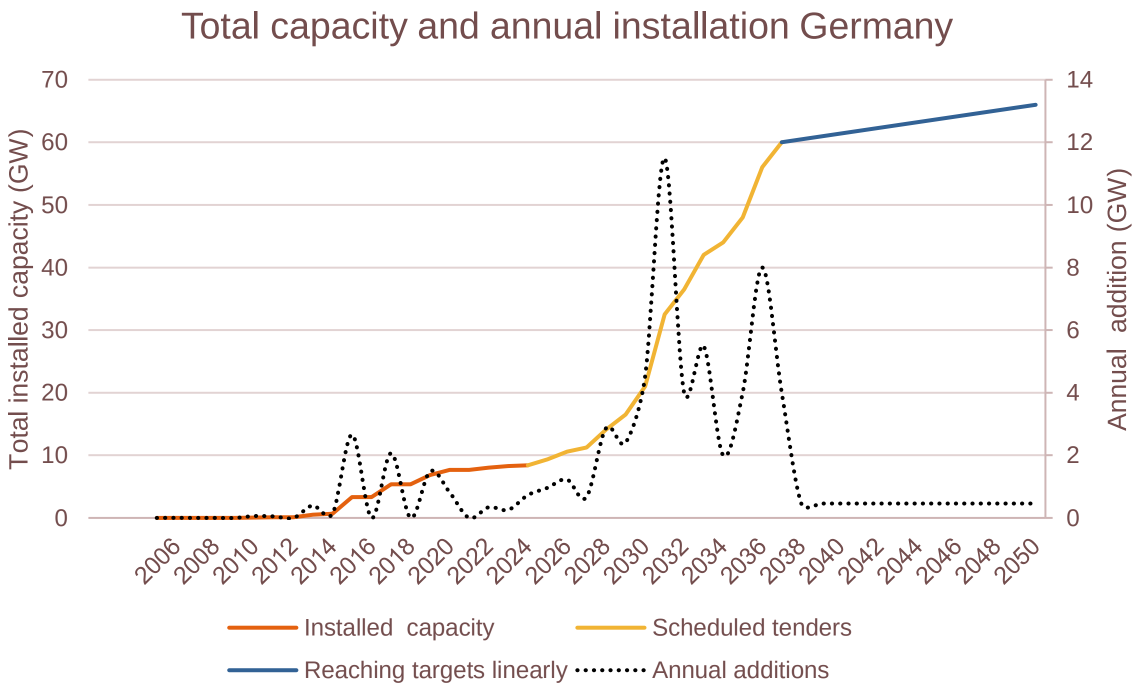


Figure 6. Source: Own calculations based on Esgian and manually collected data

Belgium

- The targets for Belgium are relatively low compared to other North Sea countries.
- There are 3 upcoming parks which will start operating in 2030 (2,5 GW). (Figure 7). This results in a significant peak in which they will almost reach their target ins 2030.
- To meet the target of 2040, only 0,23 GW newly build capacity is required. After which the annual installation is expected to reduce to zero untill 2050.

Tender planning untill	2030
Location	North Sea
Installed capacity (GW)	
2024	2,3
2030	6
2040	8
2050	8
Average time between operation and:	
foundation installation	1,5 years
lease award date	7,8 years
Type	Fixed

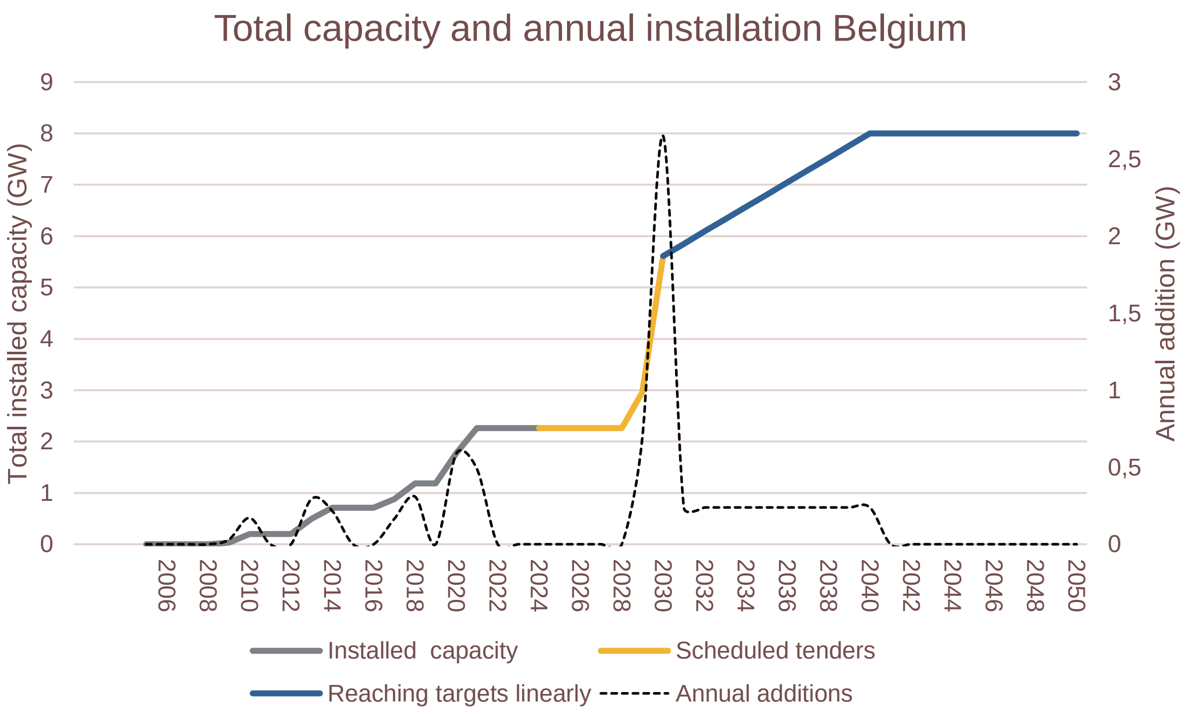


Figure 7. Source: Own calculations based on Esgian and manually collected data

UK

- The current installation capacity in the UK is the highest of the North Sea countries. Figure 8 shows the overall installations for the UK, which is not only located in the North Sea. The scheduled tenders are with fixed 75% and floating foundations 25% of the capacity.
- There is a increase expected around 2030 with almost 20 GW of new installations, reaching their target. The installed capacity will decrease significanlty after the tender planning to meet the target of 2050.
- The time between operation and lease award date is relatively high compared to the other countries. This is mainly due to their different tender processes. For the UK, the project developer is responsible for the organisation of the offshore cabling and substations required, after the tender is awarded. In comparison with f.e. Germany and the Netherlands this is already developed by the TSO before the tender is awarded.
- The time between the foundation installation date and the operational date is average.

Tender planning untill	2030
Location	North Sea & Atlantic ocean
Installed capacity (GW)	
2024	11,9
2030	50
2040	
2050	100
Average time between operation and:	
foundation installation	1,8 years
lease award date	10,4 years
Type	Fixed&Floating

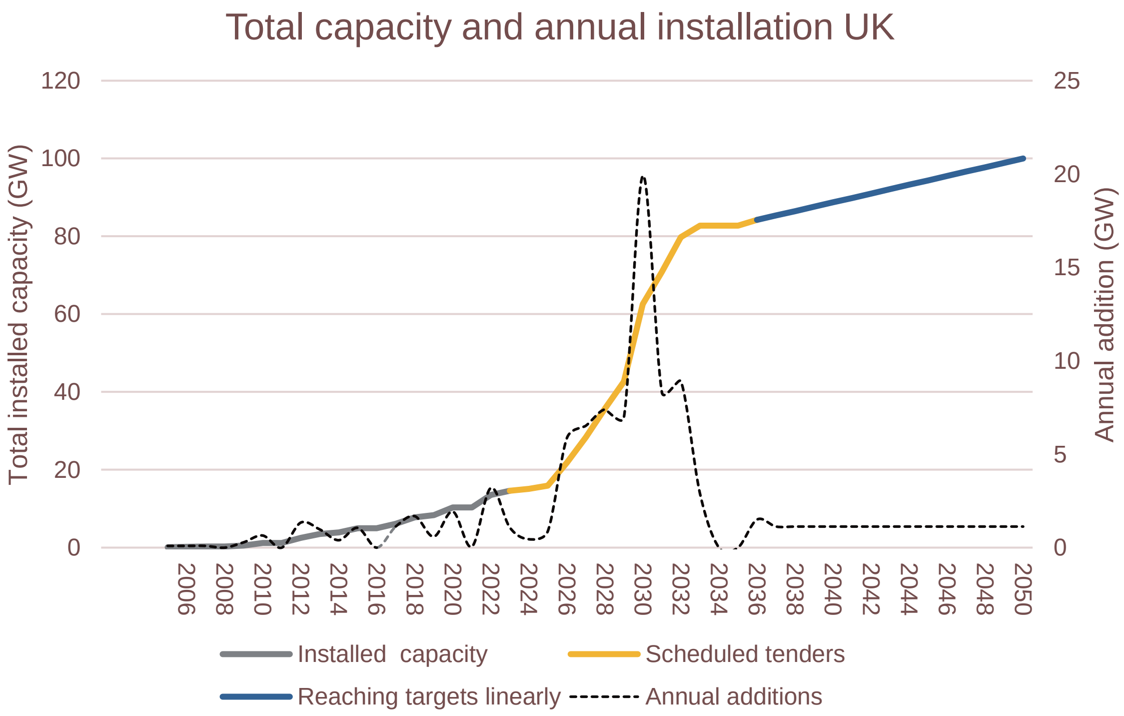


Figure 8. Source: Own calculations based on Esgian and manually collected data

Denmark

- Denmark is the first country in Europe installing offshore wind turbines.
- In 2031 there will be a high peak in installations, which 6 GW expected to start operating in 2031 (Figure 9).
- They are expected to reach their 2030, after the implementation of the 6 GW in 2031. To meet the 2040 goal however, this results in the same amount but spread over 9 years, which would cause a significant drop.
- To reach to 2050 targe, the annual new installation will increase after 2040.
- The average time between lease award date, foundation installation and lease award date is low compared to other countries.

Tender planning untill	2030
Location	North Sea & Atlantic ocean
Installed capacity (GW)	
2024	2,2
2030	12,9
2040	19,3
2050	35
Average time between operation and:	
foundation installation	1,1 years
lease award date	5,6 years
Type	Fixed

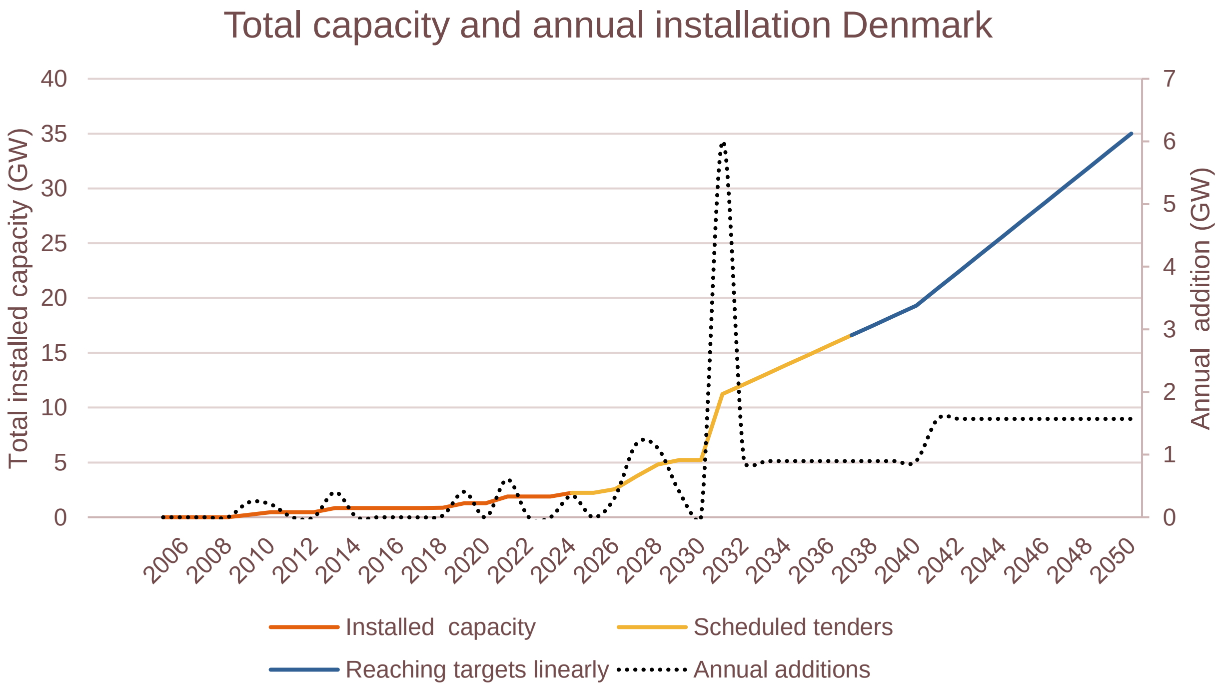


Figure 9. Source: Own calculations based on Esgian and manually collected data

Norway

Tender planning untill	2038
Location	North Sea / Barents Sea
Installed capacity (GW)	
2024	2,2
2030	12,9
2040	19,3
2050	35
Average time between operation and:	
foundation installation	1,75 years
lease award date	7,4 years
Type	Fixed&Floating

- Currently, Norway has a small amount of offshore wind turbines installed. The first large scale offshore wind park 1,5 GW, will start operating in 2031, which is the only scheduled fixed wind park. The next scheduled windpark will solely consist of floating wind turbines, the first large scale floating wind park (1,5 GW) will start operating in 2033.
- With the current planning Norway is not on track to reach the 2030 target, this results in a high capacity which should be added after the tender planning to meet the 2040 target (Figure 10), which is around 3,5 GW each year. In the project data there were other offshore wind parks listed but there operational date was not yet determined and therefore not taken into account in the scheduled tenders.
- Norway possitions as the leader in the floating ofshore wind sector. It benefits from a strong offshore supply chain due to the advanced oil and gas industry, and deep water ports and therefore floating technology does have significant growth potentional in Norway. (Offshorewind.biz, 2024)
- Norway is innovating in mainly foundations to increase the proficatability of the Floating technology. (WindEurope, 2024a)

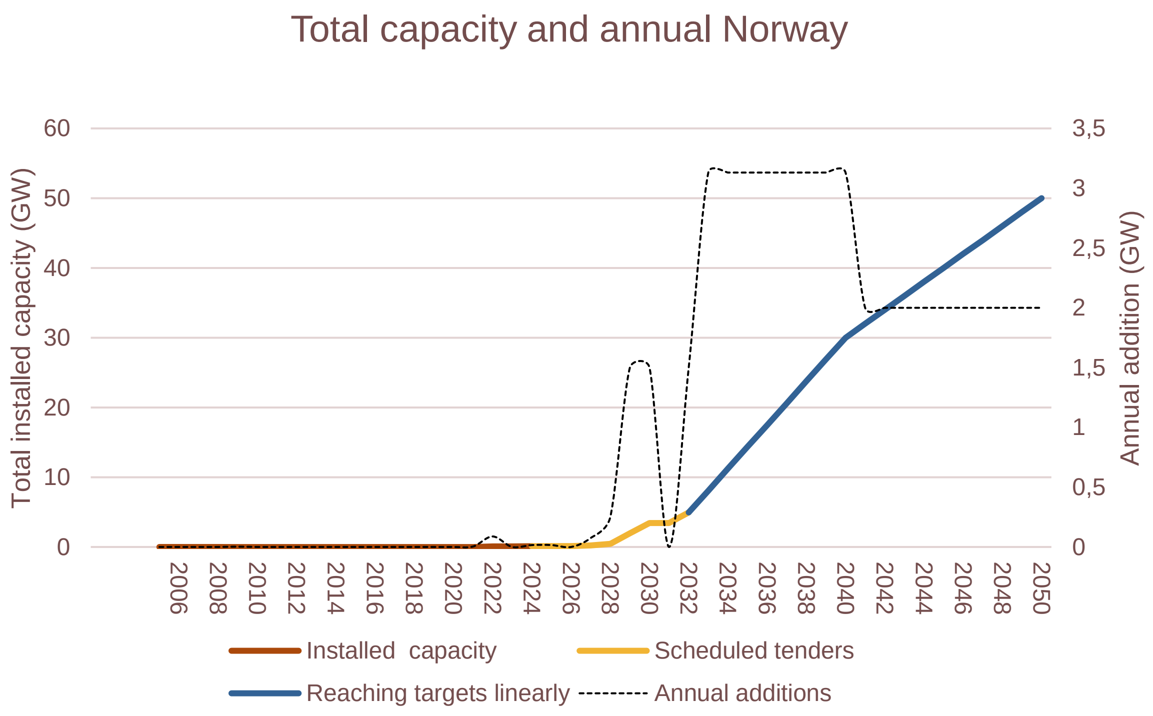


Figure 10. Source: Own calculations based on Esgian and manually collected data

North sea total installation capacity

- The upper panel of Figure 11 visualizes the total capacity of the all the windparks in the North Sea, including fixed and floating turbines.. UK is expected to install the largest capacity, and Germany and NL the second capacity, however NL is expecting scale up later on.
- The annual installed capacity which is which is required to meet the targets is presented in the figure below. There is a high variability in the expected annual installed capacity. There is a high peak for around 2030-2031, primarily caused by the high expected installation of the UK, Germany and Denmark.
- The second peak around 2036-2037, is primarily caused by Germany, NL and Ireland. After 2040, the yearly installation is expected to decrease significantly.

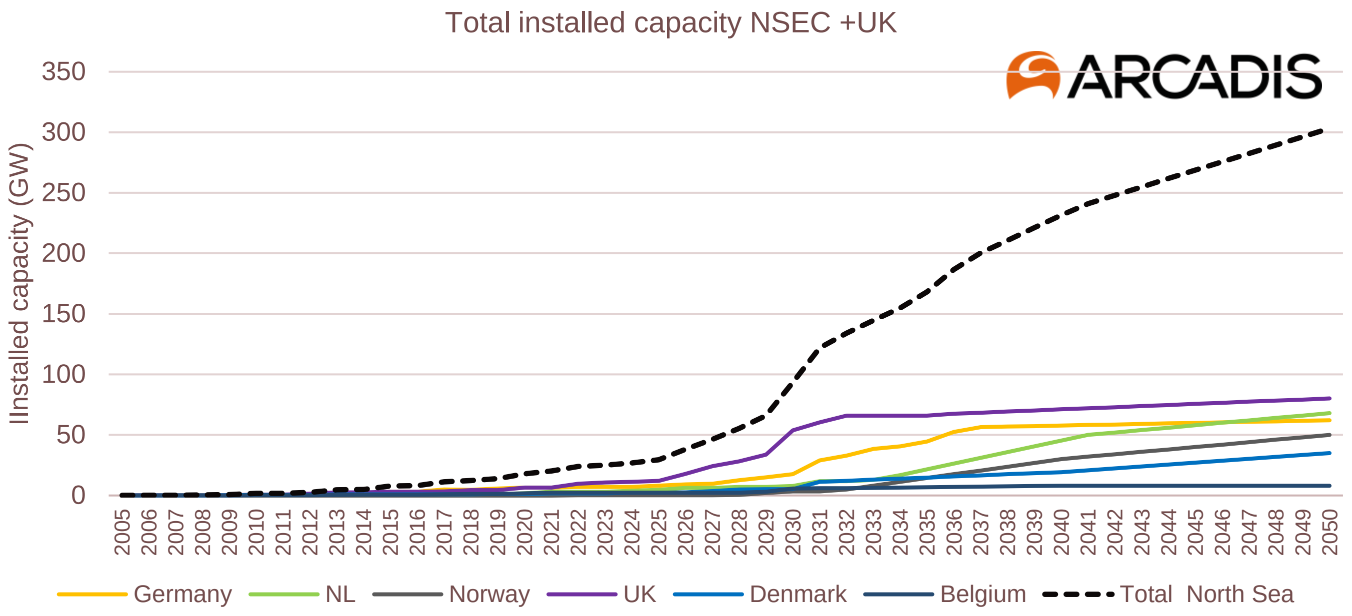


Figure 11. Source: Own calculations based on Esgian and manually collected data

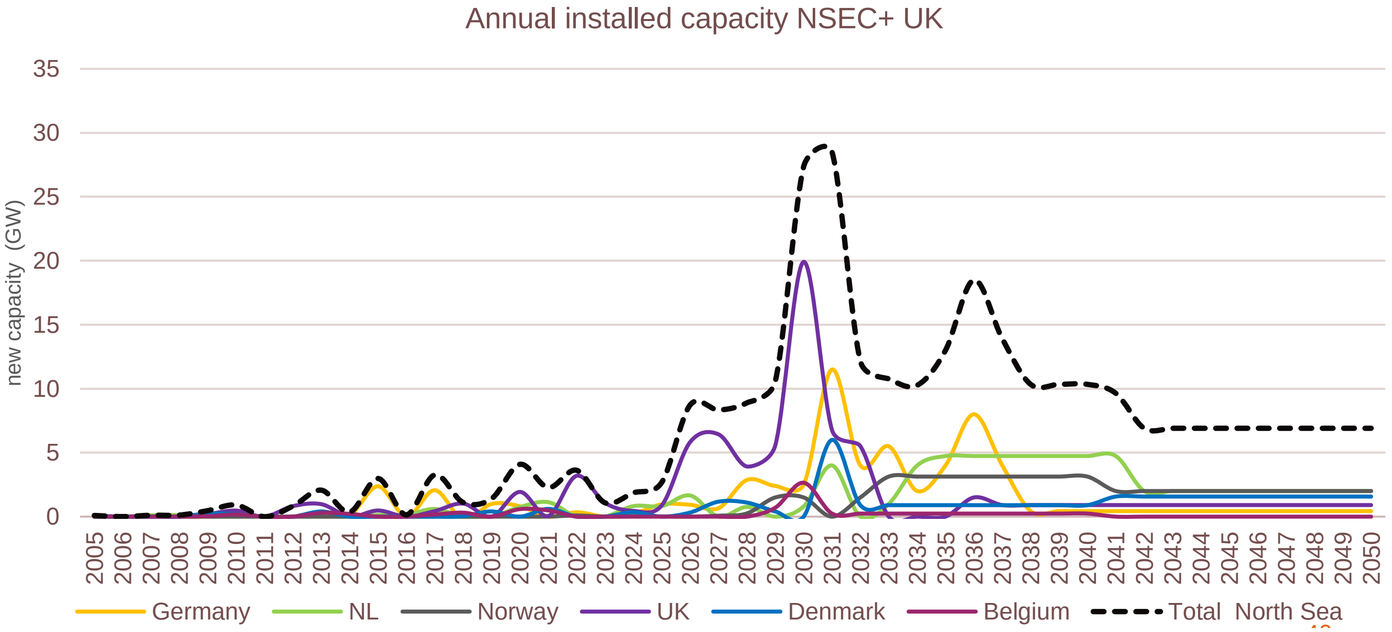


Figure 12. Source: Own calculations based on Esgian and manually collected data

Floating

- In figure 13 the share of fixed and floating turbines are plotted considering the wind parks in the tender schedule. The peak of the new annual installations for floating will be later compared to the peak for fixed turbines.
- The GWEC predicts the commercialization of floating wind will be achieved around 2029-2030. There are challenges with floating foundations related to the high prices compared to the fixed installations. In addition, they need appropriate port infrastructure and vessels for the mooring installations which are scarce. The UK is expected to install the highest amount of floating wind turbines globally. (GWEC, 2024)

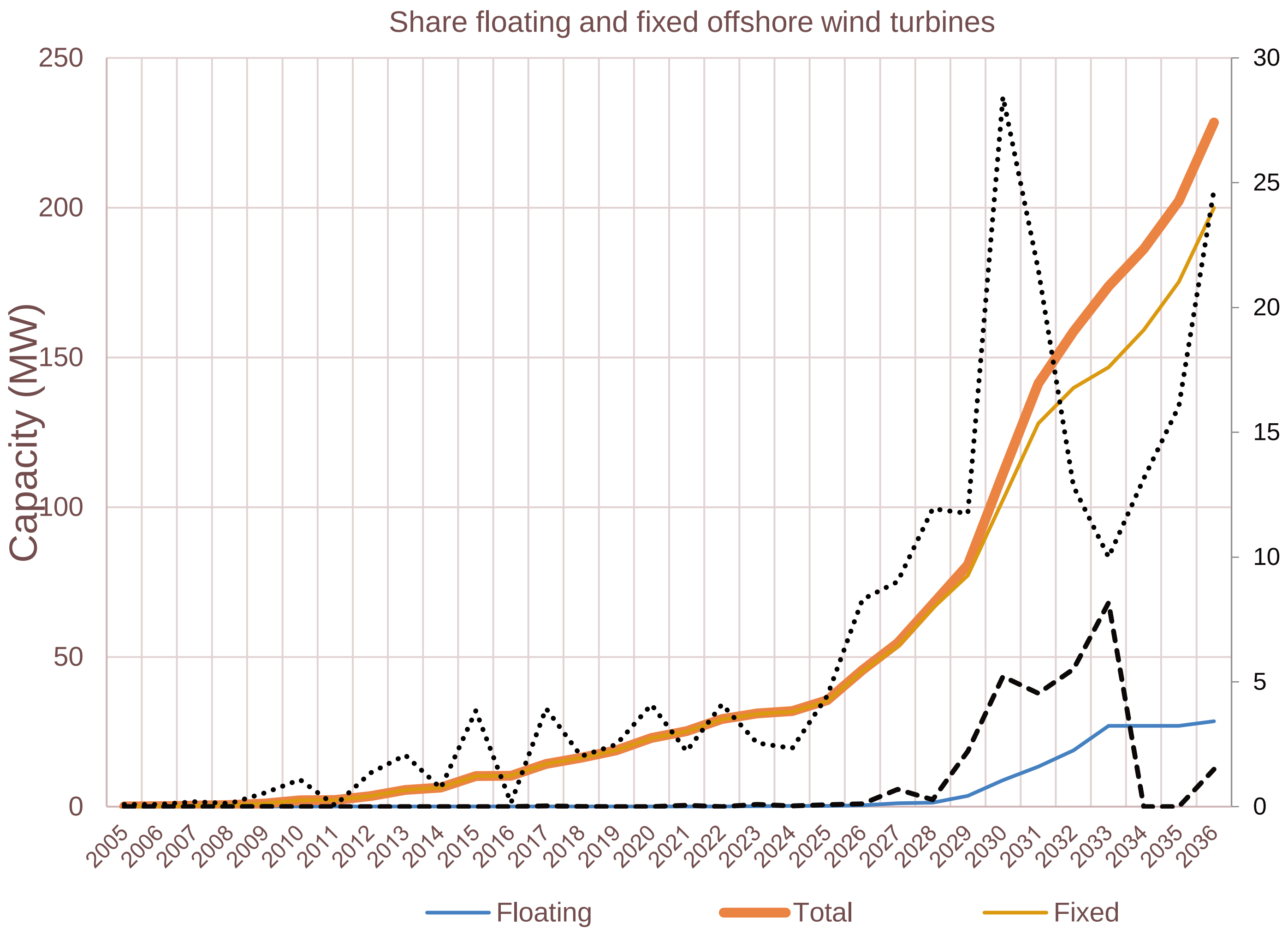
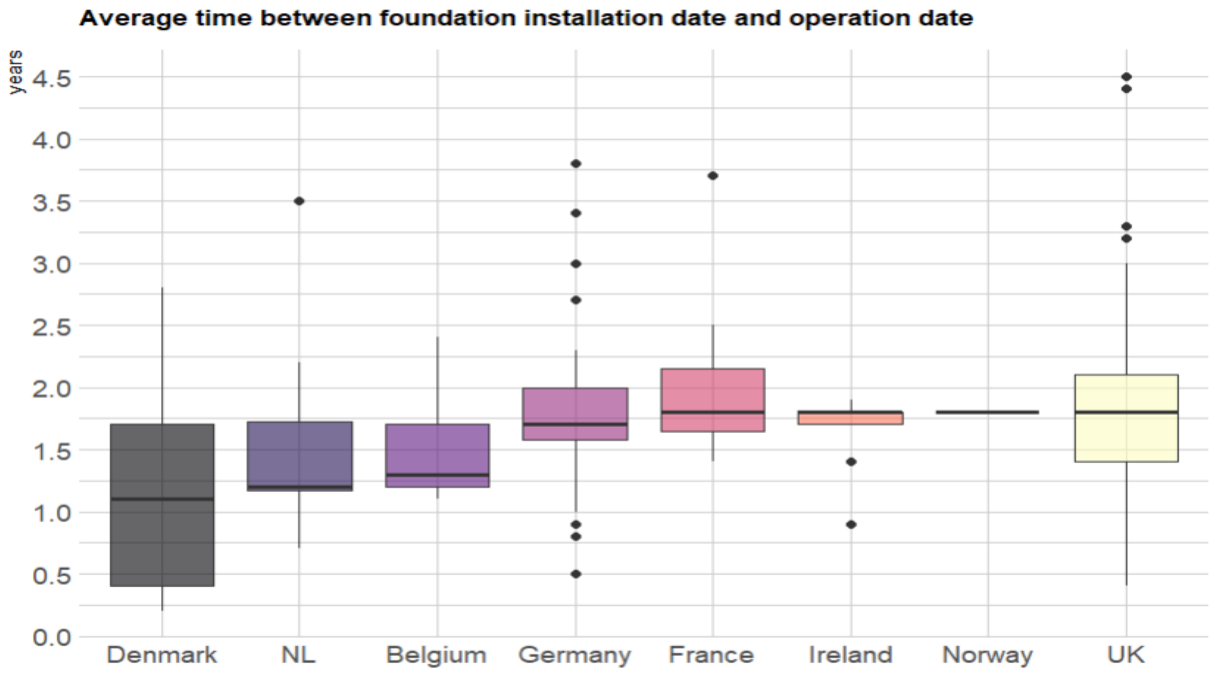


Figure 13. Source: Own calculations based on Esgian and manually collected data

Time between installation and operation date

- Based on the manually matched and extended data, it is possible to study the distribution of time between the installation and operation date of offshore wind parks across the countries. Box plots are shown to provide an overview of the durations. Countries are sorted based on their median time. We can see that the time between installation and operation date varies strongly, with upwards outliers around 3 years. Both in terms of time between foundation installation and operation date and lease award date and operation date, Denmark and the Netherlands are coutnries where offshore wind parks are realised relatively quickly. Across all countries, most projects require a duration around 1.5-2 years between foundation installation to operation. Countring from the lease date, the realisation duration becomes significantly longer, adding 4-9 years to the project duration.
- The significants variations in duration across countries are important to identify, they provide insights in the time available for the indust to optimize their planning while meeting the targets. Within these timeframes, the industry can evaluate to what extend they can reschedule their operations in order to achieve supply chain efficiencty.



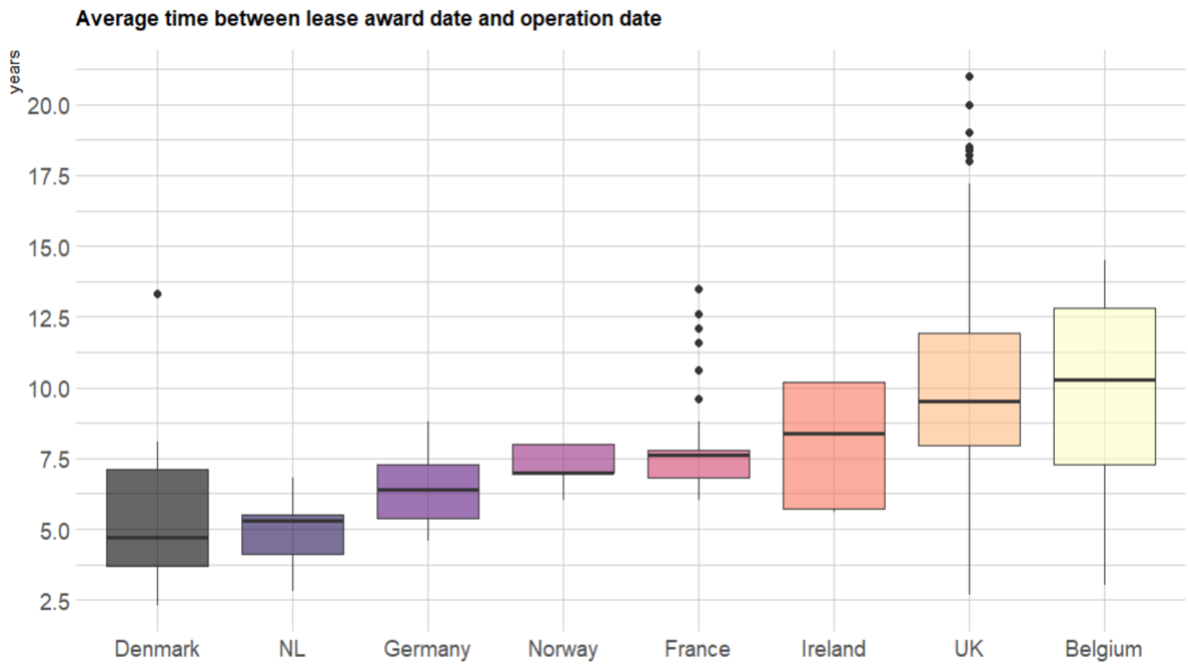
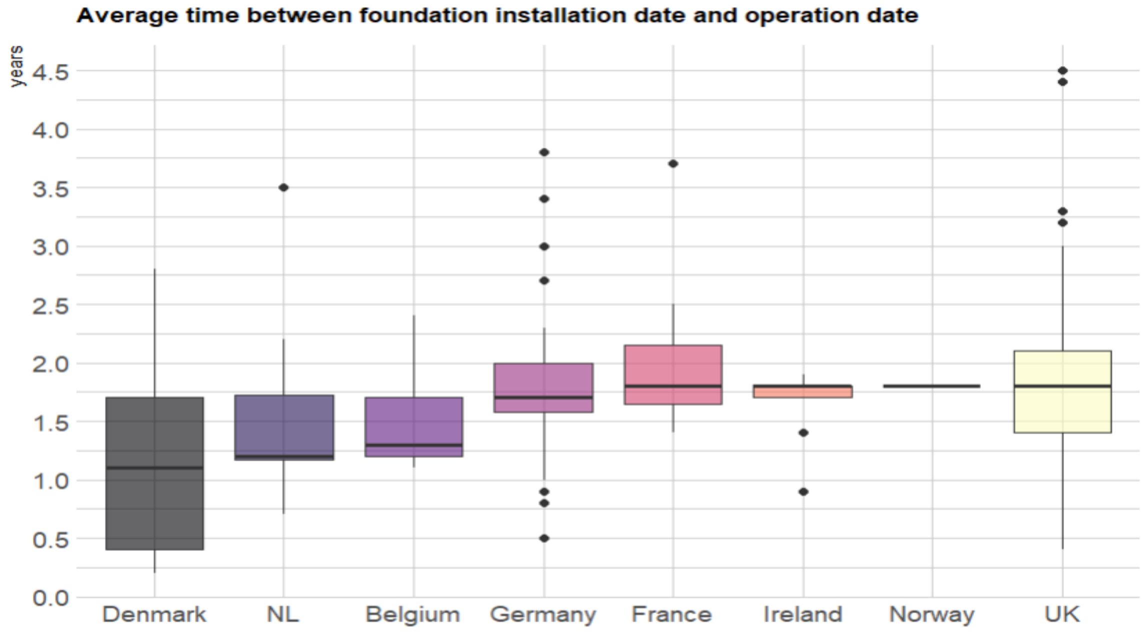
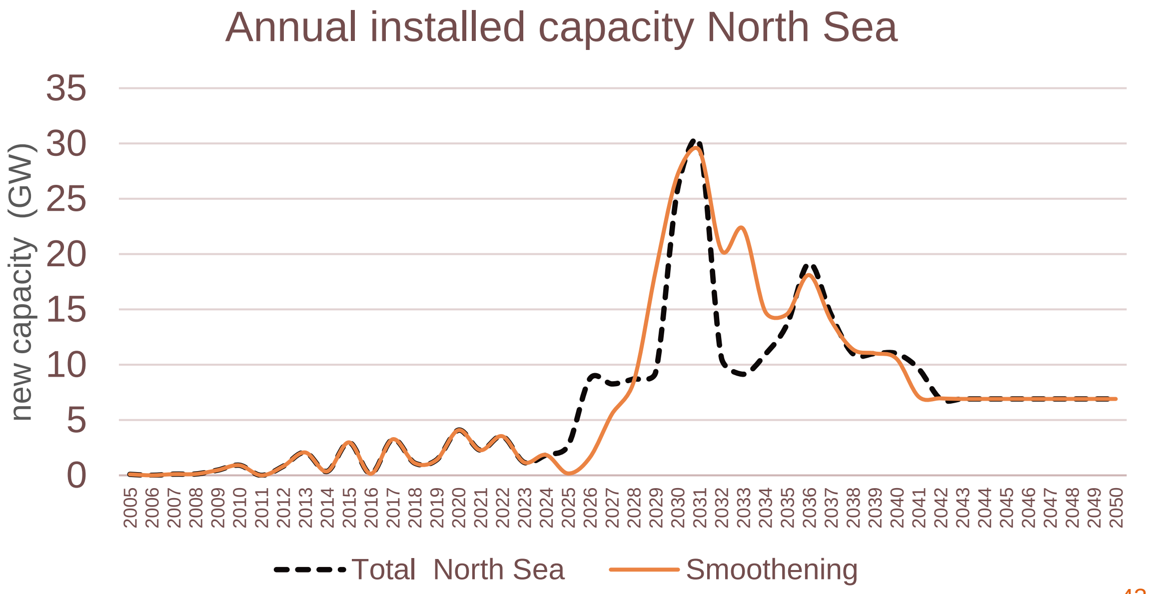


Figure 14. Source: Own calculations based on Esgian and manually collected data

Uncertainty timing operation

- The boxplots show uncertainty in the time between foundation installation and operation
- The high fluctutations are therefore corrected with uncertainty shown in the boxplots.





Comparision installation dates and operation date

Figure 14, annual start date of the foundation installation date is compared with the annual addition of operational installed capacity.

In figure 5-13, the operational date is considered as the starting date for the annual new installation. To optimize the supply chain planning, it is valuable to identifty the timing of the activities required before the wind parks starts operation.

The start of the wind foundation installation date is reflected in the figure. This is however not reflecting the total amount of foundations installed each year, due to the timeframe of 1,5-2 year. Ideally you would plot the figure in a way the duration of installation, identified in the boxplots, is reflectected in the figure.

It would be valuable to indentify the benefits of spreading the peak in annual installation capacity, such as the impact on marine life. When installing an high amount of foundations at the same time, marine life will be increasingly affected.

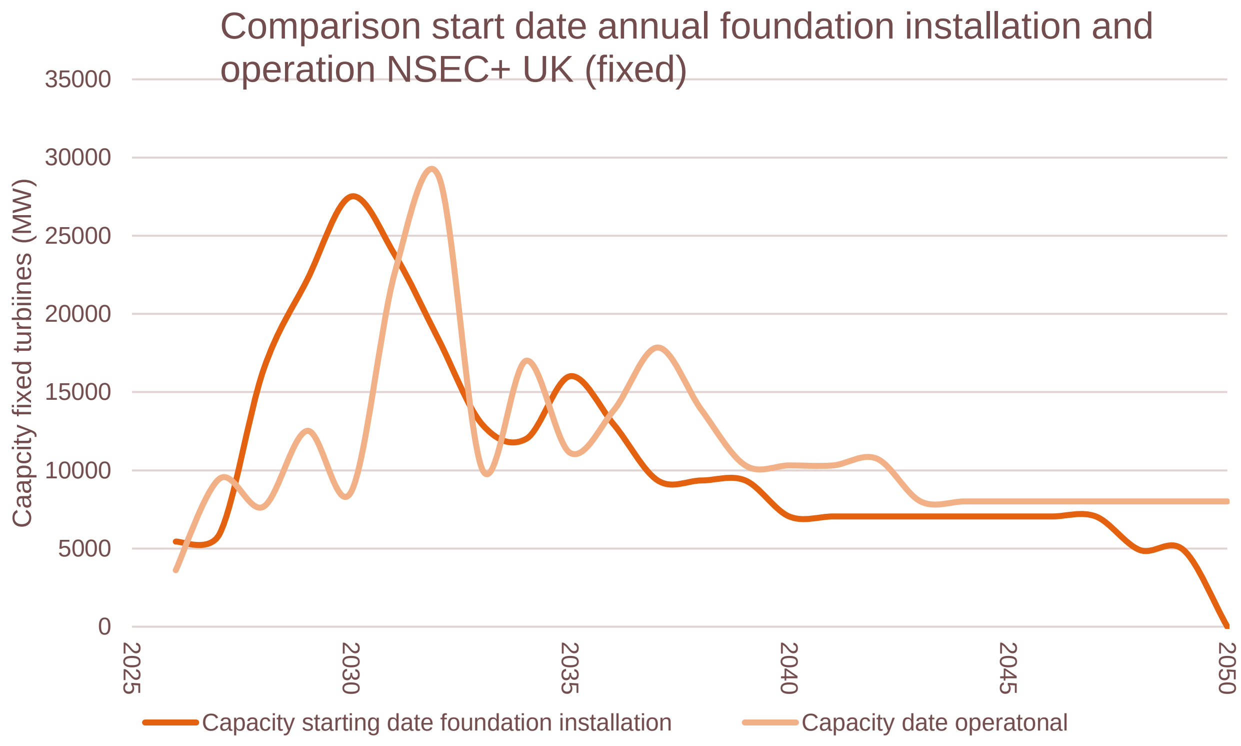


Figure 15. Source: Own calculations based on Esgian and manually collected data

The following method is used for the creation of figure 15; This only takes into account the fixed turbines, because the foundation for fixed and floating differ. This figure takes into account the upcoming capacity off the NSEC countries, excluding Ireland, since there is no data available. The data between the foundation installation date and the operation date of past projects and the upcoming tenders are used for this plot. The average time between this dates is calculated for each country. In case there was no availble date for operation or foundation installation, an approximation of the date is calculated using the average of the country. When there was no data available for both dates (only for future projects) the capacity is not taken into account. The tender planning of the countries will go up to 2030-2037, dependent on the country. Beyond the tender planning, the annual additions are calculated in order to meet the coutries targets up to 2050. The foundation installation start date is after the tender planning is therefore calculated with the average of the time between foundation installation and in the scheduled projects.

Conclusion

- This study examines the outlook for offshore wind capacity in the North Sea, from the first build wind parks until the target set for 2050. It uses data on the offshore wind capacity targets of different countries, alongside information about scheduled wind parks, to forecast the annual installation capacity in the region. The findings reveal that the peak of installation capacity is expected to occur around 2030-2031, with a second peak projected for 2036-2037. The second peak will be partially driven by floating turbines. The UK is expected to lead in capacity installation, followed by Germany and the Netherlands. However, after 2037, the rate of new installations will decrease, and by 2040, this decline will be even more pronounced.

- A key issue highlighted in the study is the uncertainty surrounding the ability to meet the 2030 targets. Meeting the 2030 target is seen as unrealistic based on other studies and requires substantial investment to scale up installation capacity. This research underscores the importance of planning beyond the existing tender schedule in order to increase the likelihood for meeting the 2030 targets. The study suggests that the expected drop in annual installations after the current tender schedule ends (2036) will create significant uncertainty for investments needed to scale up installation resources, particularly installation vessels. These vessels require substantial investment, and their operators need assurance that they will be utilized throughout their expected lifespan of 25 years.

- This study identifies the need for improved coordination between countries to optimize the installation rates for offshore wind in the North Sea. There is potential for improving the efficiency of installation processes by coordinating efforts more effectively.

- Policymakers are encouraged to focus on the planning that extends beyond the current tender schedules. By addressing these challenges and improving coordination, the study emphasizes that the offshore wind industry can better navigate the uncertainty and reach the ambitious capacity targets set for 2030 and beyond.

Limitations - Decommisioning

When assessing the installed capacity, it is assumed all the wind parks will still be operational by 2050. Given the standard industry lifetime of 25 years (TKI, 2022) , this is unrealistic and therefore lead to an underestimation for the required installed wind capacity between 2040 and 2050. The decommissioning is not taken considered in the outlook due to the following uncertainties.

The project developers have several option for the aged turbines, including lifetime extension, decommissioning and repowering (Janipour, 2024). Currently, the number of decommissioned wind parks is low, 4,95 GW in the last ten years in Europe. Lifetime extension of 5-15 years will result to the lowest LCOE. However, there are uncertainties about the technical feasibility and the LCOE advantage is relatively small.

More wind parks reach the end of their lifespan around 2040, and this number will continue to grow looking at the increase in new installation over the years. It remains difficult to predict whe these wind parks stop operating, due to the options for of project developers. For future research, the impact of the decision — whether turbines are repowered, extended, or decommissioned on long term planning will be valuable.

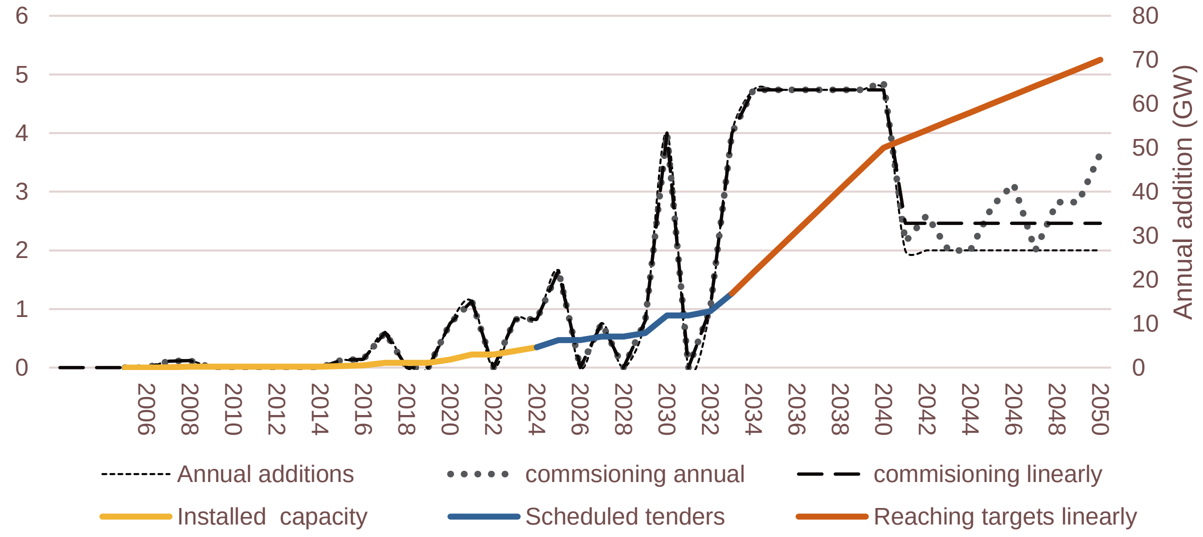
An example calculation for offshore wind planning of the Netherlands reaching 2050 targets, is shown in the figure. The difference in new annual installations after 2040 using two methods can be observed.

- Annual commissioning: Adds the capacity of the decommissioned wind parks to the annual new installation calculation after the tender planning, assuming the wind park will be operational for 25 years. For example, the new installed capacity of 2049 would include the capacity installed in 2024, this result in large fluctuations moving to 2050.

- Linear commissioning This method assumes the current installed capacity (2024), will be distributed evenly across the years between 2040-2050.

While the first method shows the large fluctuations which might be unrealistic, the second method does not consider the specific age of the wind farms.

Total capacity and annual installation NL



Source: Own calculations based on Esgian and manually collected data

Limitations

Operating in international environments

- The companies, the European supply chain operated in an international environment. When the peak of the North Sea is expected to decrease after the schedules tender of the North Sea, the demand for the resources may still be equal, due to other offshore wind projects across the world.
- However, the drop in expected demand for the North Sea, increases the risk for the European companies, since the North Sea is a relatively large market. The overall risk for European companies adds up amongst other risks identified during the interviews in the first part of the research. Such as the rapid scale up of Chinese installation resources, which are expected to fill in the possible gaps in installation resources. (GWEC, 2024).

Inaccuracies in the Esgian data

- Some inaccuarcies is the Esgian data were found. Some of the operational dates were not consistent with external data sources. Some of the data was adjusted with an alternative datasource, when the external data sources seemed more accurate. While some of the dates were adjusted, not all the data was cross checked with other data sources due to the large number of parks. Additionally, some scheduled parks were missing and manually added to the datasheet.

Recommendations for further research

To study the next steps of the development of the masterplan can be approached in two ways, which have been partially covered in this study. For further analysis is essential to quantify the supply chain capacity (partially done in appendix) and align this with governmental targets to indentify the critical contraints.

1. Top-down analysis:

• Combining government tenders and sector targets across North Sea countries (partially done for government tenders; see “North sea total installation capacity”)

• Sensitivity analysis by studying impact and scale-up of multiple demand sectors, i.e. industry electrification

and scale-up of green molecules (see also technical bottlenecks)

• Condensing the above into a realistic offshore wind installation scenario

2. Bottum-up analysis:

• Study the current state of supply chain quality and efficiency by identifying the key bottlenecks in every

step of the chain - (partially done; see also technical bottlenecks)

• Identify what bottlenecks could be solved by improving coordination and planning. Describe the impact on

1) costs, 2) lead-times, 3) risks and 4) scale up potential.

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Appendix

Appendix A: Results: Overview of targets countries NSEC+UK

Appendix B: Total installation capacity NSEC + UK

Appendix C: France

Appendix D: Ireland

Appendix E European offshore wind size forecast

Appendix F: Comparing projections to resource capacities 1. Installation vessels

Appendix G Comparing projections to resource capacities

Appendix H Interview questions

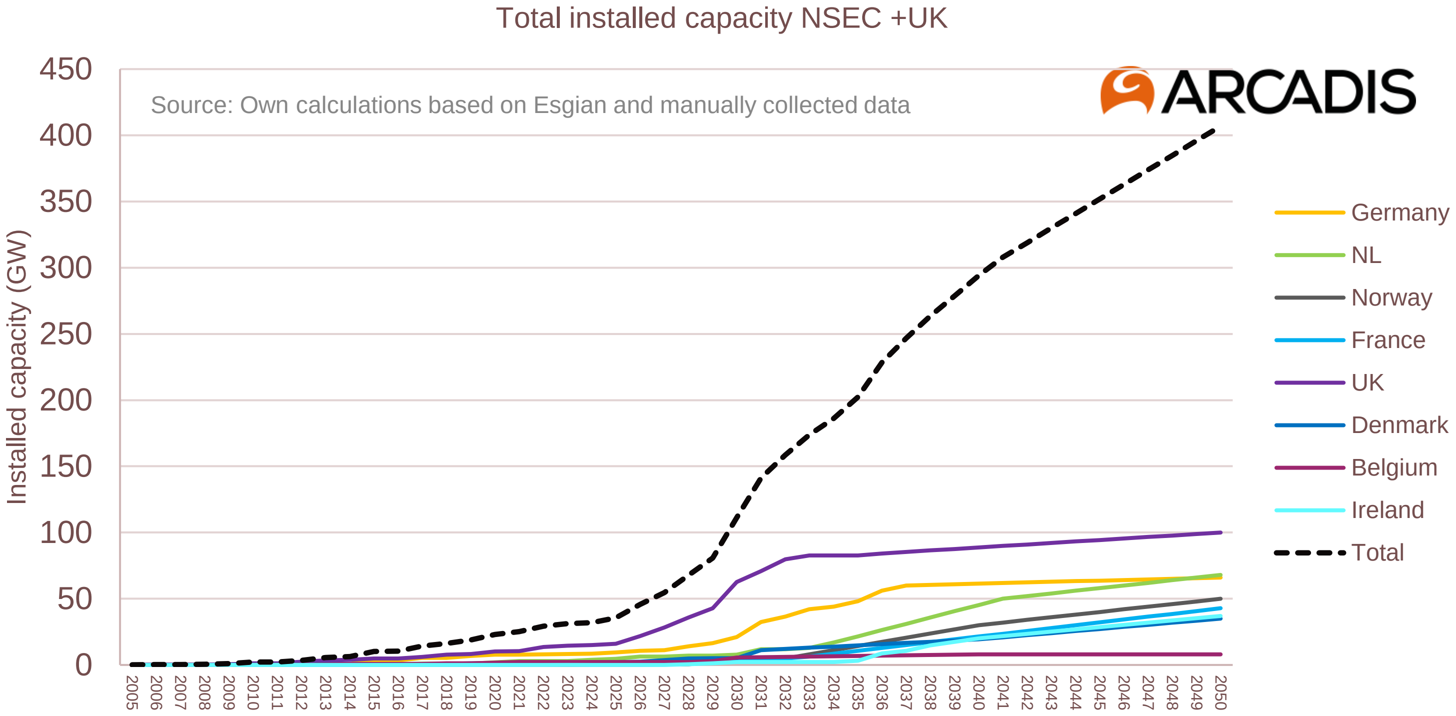
Appendix I: Assumptions

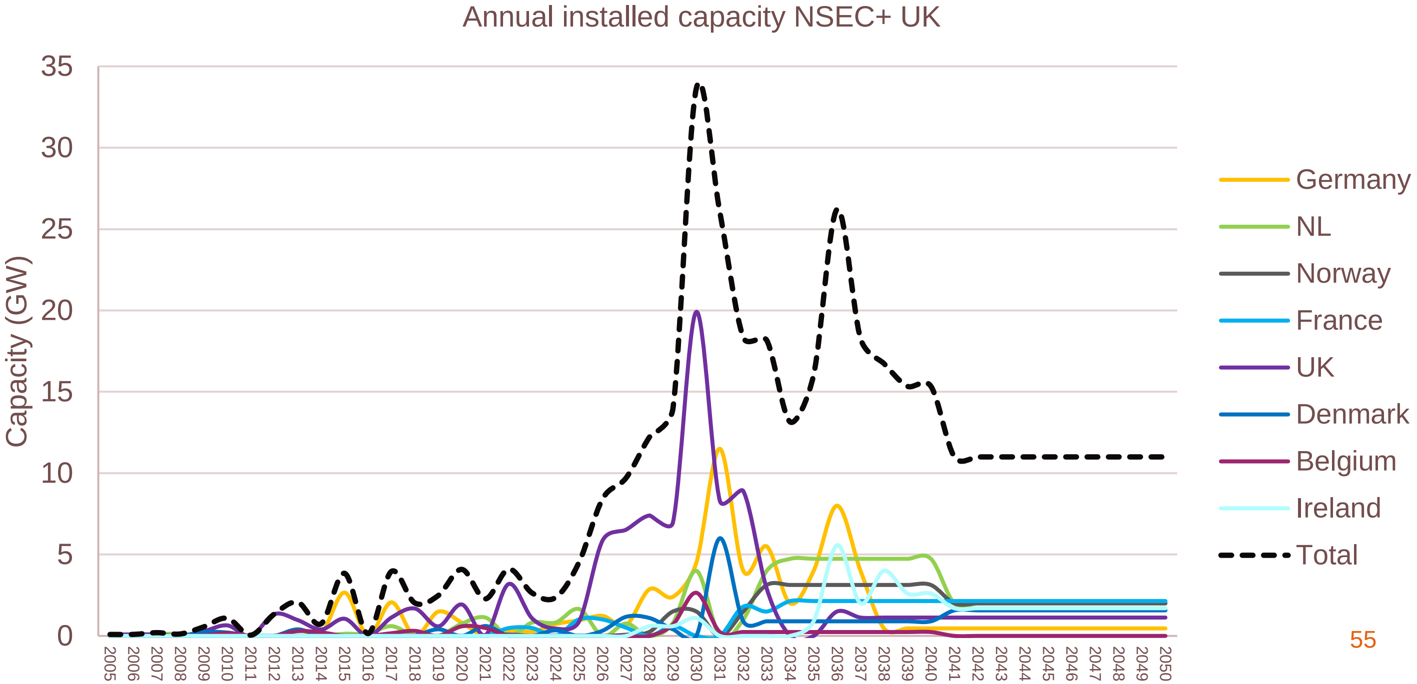
Appendix A: Results: Overview of targets countries NSEC+UK

Country	Targets (GW)		
	2030	**2040**	**2050**
UK	50 (GOV.UK, 2023)		100 (Esgian)
Belgium	6 (circabc, 2024)	8 (circabc, 2024)	8 (circabc, 2024)
NL	21,5 (2032) (RVO, 2024)	50 (RVO, 2024)	70 (RVO, 2024)
France	18(2035) (WindEurope, 2024)		45 (WindEurope, 2024c)
Ireland	5 (GOV.ie, 2024)	20 (WindEurope 2024d)	37 (WindEurope 2024d)
Norway		30 (WindEurope, 2022)	50 (WindEurope, 20220)
Denmark	12,9 (Rystad energy, 2023)	19,3	35
Germany	24,6 (circabc, 2024)	60 (circabc, 2024)	66 (circabc, 2024)

Appendix B: Total installation capacity NSEC + UK

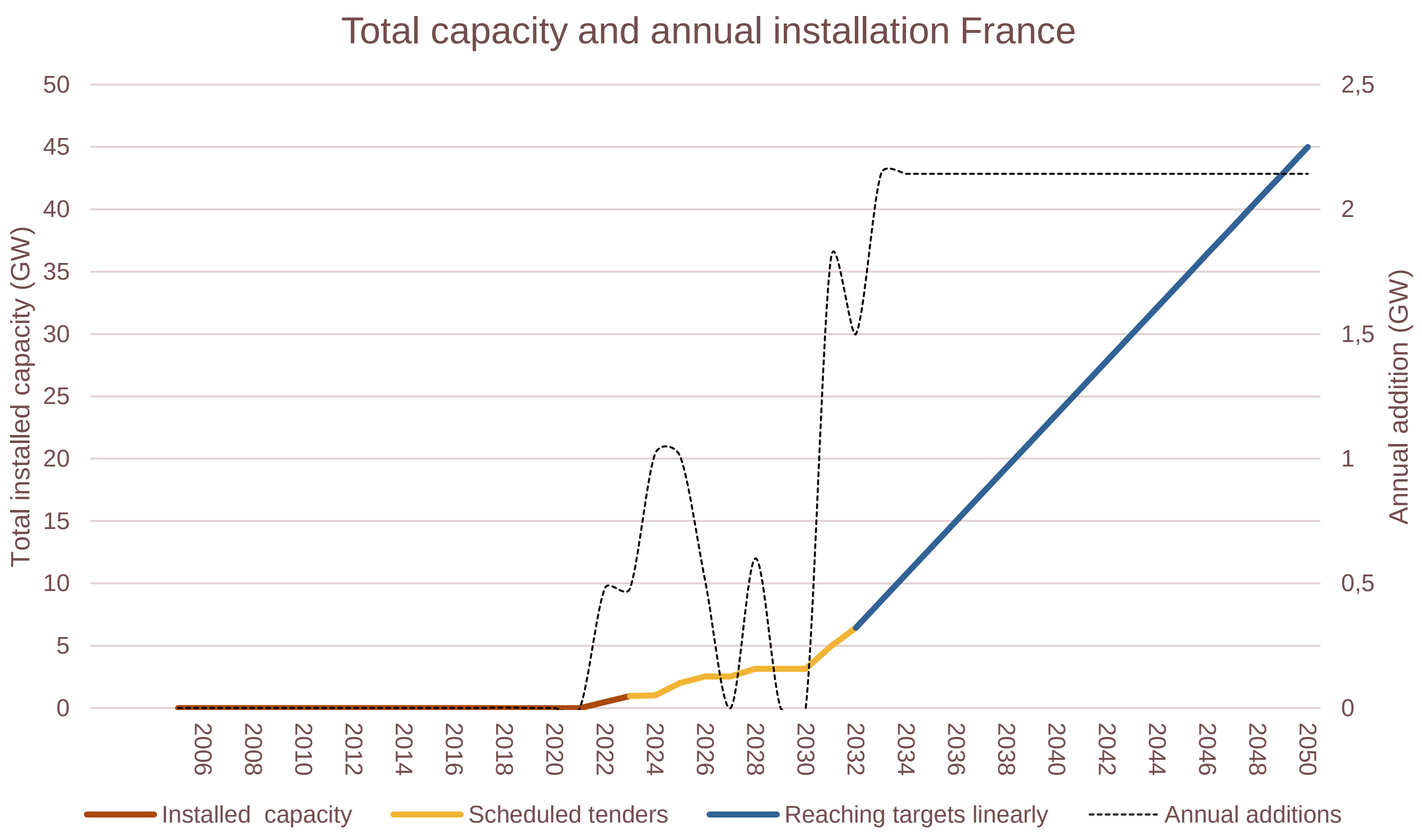
- The upper panel visualizes the total capacity of the all the NSEC countries and the UK, including fixed and floating turbines. The figure above show the total capacity of offshore wind turbines, combining all the targets which will result in 407 GW in 2050. UK is expected to install the largest capacity, and Germany and NL the second capacity, however NL is expecting scale up later on.





Appendix C: France

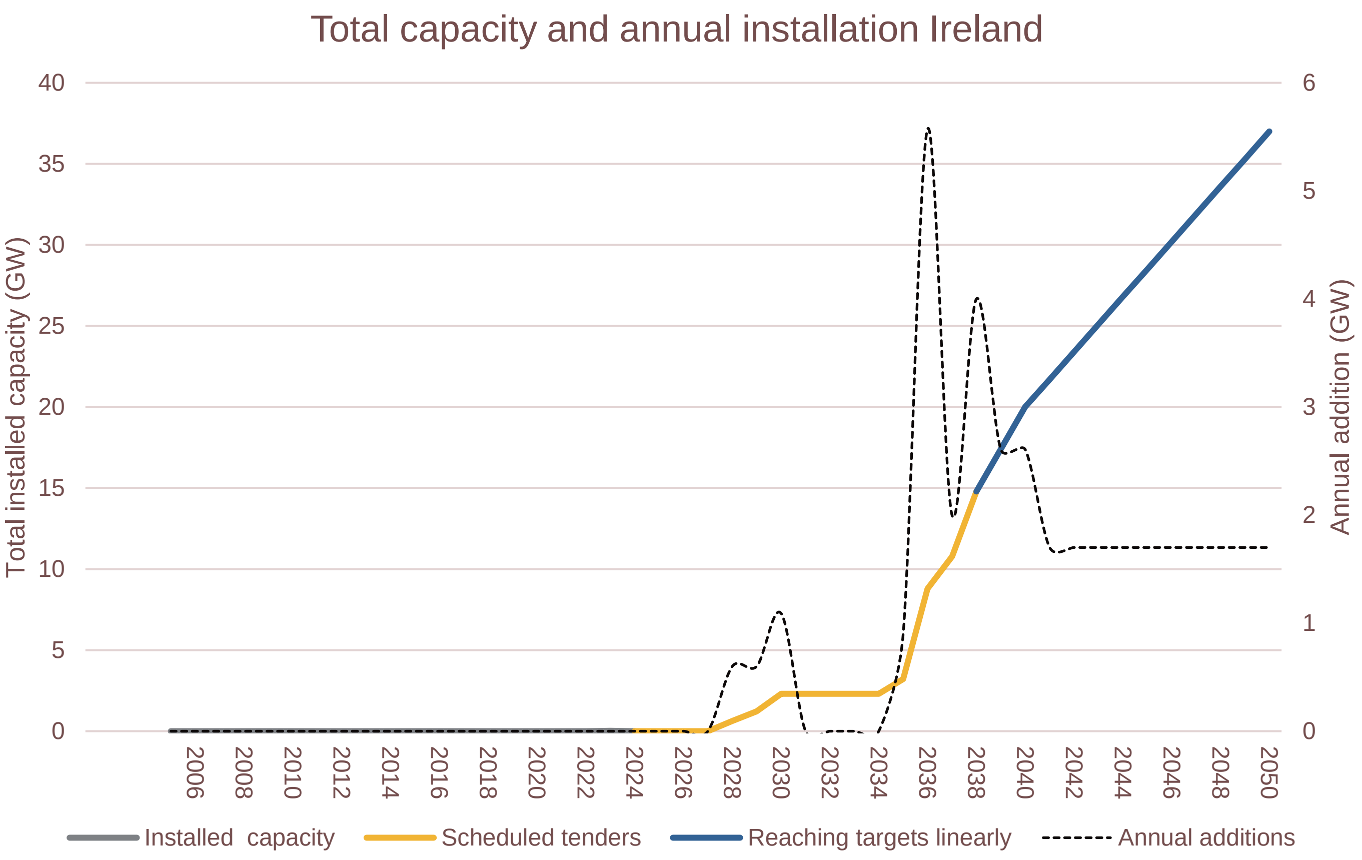
Tender planning untill	2030
Location	Atlantic ocean
Installed capacity (GW)	
2024	2,2
2030	12,9
2040	19,3
2050	35
Average time between operation and:	
foundation installation	2,1 years
lease award date	7,9 years
Type	Fixed&Floating



Source: Own calculations based on Esgian and manually collected data

Appendix D: Ireland

Tender planning untill	2038
Location	Irish Sea
Installed capacity (GW)	
2024	2,2
2030	12,9
2040	19,3
2050	35
Average time between operation and:	
foundation installation	8,1 years
lease award date	1,5 years
Type	Fixed&Floating

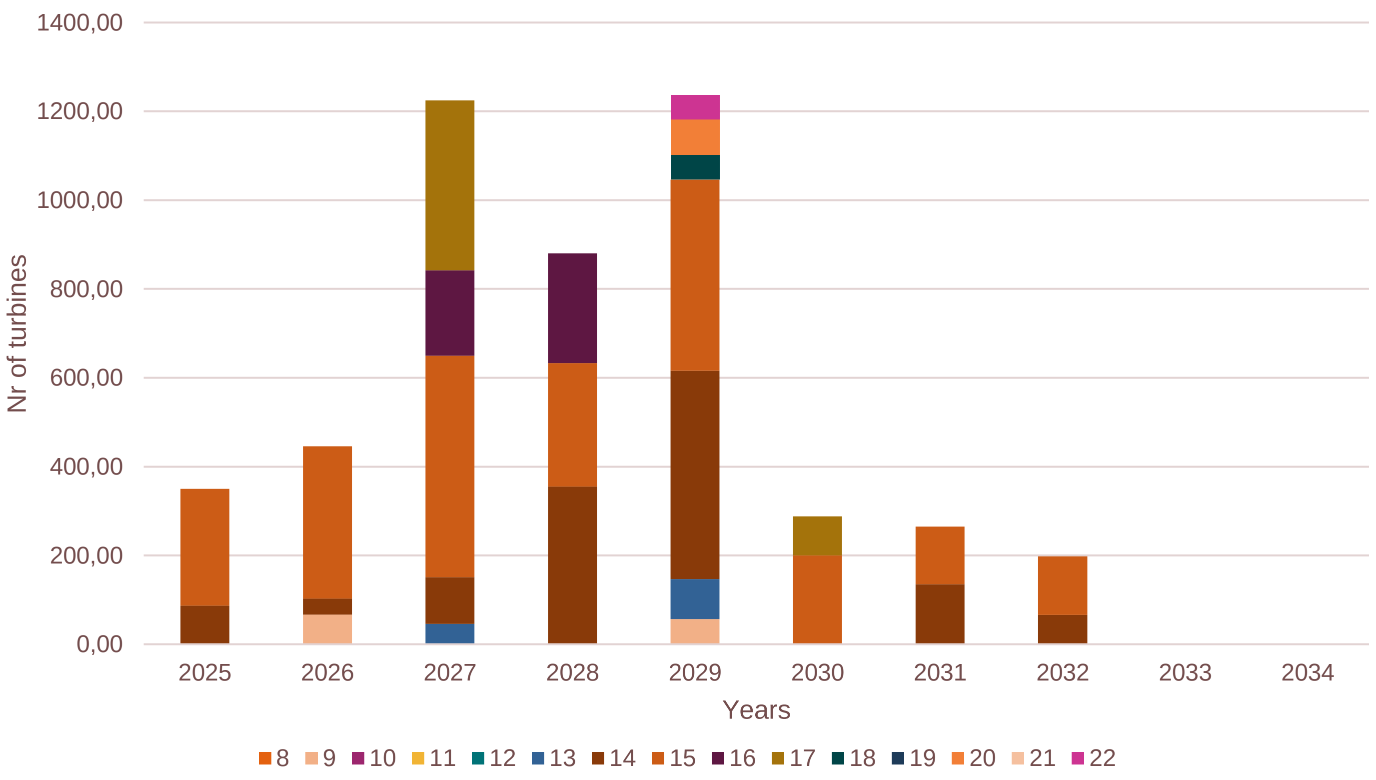


Source: Own calculations based on Esgian and manually collected data

Appendix E European offshore wind size forecast

In the Esgian data, for some wind parks, the turbine size was specified. The average capacity of the turbines for the upcoming tenders was calculated and plotted over time.

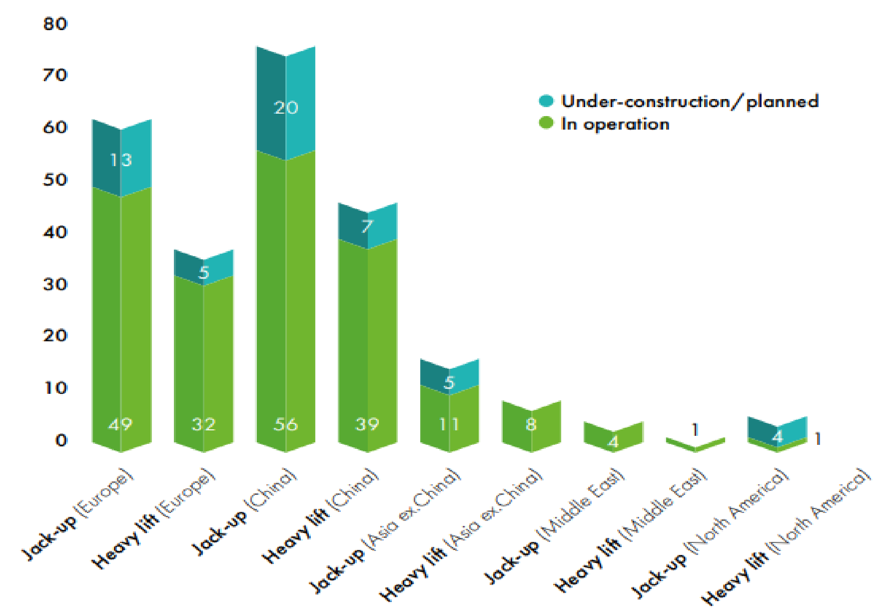
The average was 15 MW. When there was no turbine size availble, 15 MW was assumed.



Appendix F: Comparing projections to resource capacities 1. Installation vessels

The amount of wind turbine installation vessels is presented in the figure below, the amount of jackup installation vessels in operation in 49 in operation and 13 under construction. For heavy lift vessels is 32 in operation and 5 under construction in Europe in 2023. Heavy lift vessels are mostly used for foundations. For the global demand for offshore WTIV no bottlenecks are expected until 2026 (GWEC)

Overview of offshore wind turbine installation vessels in 2023



Source: GWEC Market Intelligence Global Offshore Wind Turbine Installation Vessel Database, September 2023

	Installation vessels	Europe	China	ROW	total
Jack up	in operation	49	56	16	121
	under construction	13	20	9	42
heavy lift	in operation	32	39	9	80
	under construction	5	7	0	12

Appendix G Comparing projections to resource capacities

Nacelle capacity – GWEC 2024

Region	2023e	2024e	2025e	2026e	2027e	2028e	2029e	2030e
Europe	5760	2955	7002	10036	12143	15403	21440	25950
China	10000	12000	12000	15000	15000	15000	15000	15000
APAC excl. China	1751	1569	2884	2615	3855	4770	6900	7900
North America	535	1660	3780	4750	4460	4500	4500	5000
LATAM	0	0	0	0	0	0	500	1000
Global	18046	18184	25666	32401	35458	39673	48340	54850

Foundation capacity – GWEC 2024

Region	2022	2023e	2024e	2025e	2026e	2027e	2028e	2029e	2030e
Europe	347	509	252	551	734	732	1097	1306	1639
China	683	887	1263	1411	1324	1210	1154	1071	1000
India	0	0	0	0	2	0	34	34	68
APAC excl. China & India	271	241	223	263	229	253	277	288	345
North America	0	42	73	193	294	339	308	294	270
LATAM	0	0	0	0	0	0	0	0	108
Africa & ME	0	0	0	0	0	0	0	0	0
Total	1301	1679	1811	2418	2583	2534	2870	2994	3430

Appendix H Interview questions

These were the overall interview question which was send to the interviewees in advance.

1. What are currently the biggest cost factors and risks for (companies name) in the offshore wind sector?
2. What bottlenecks are you encountering when scaling up offshore wind projects?
3. What are the consequences of these bottlenecks for your company?
4. What possible solutions do you see to address these bottlenecks?
5. Which parties are essential to come to a solution?

Appendix I: Assumptions

1. For Germany and the UK, the scheduled wind parks are also planned on other locations than the North Sea. The share of installed and scheduled wind parks located at the North Sea is calculated for the UK and for Germany. A new country target is calculated assuming the same share of wind parks will be located in the North Sea beyond the tender planning.
2. There are multiple data sources available which have different quantities each year. The quantities are changing each year, there are a lot of projects delayed or cancelled due to multiple challenges.
3. The data set Esgian provides data of wind parks in all stages of project development. In order to, provide a clear overview of the current capacity of the offshore wind parks, the decommissioned and suspended projects are deleted.
4. For the comparison between the tender and the operational date, the date of the lease round award date is chosen, instead of the lease round open date, lease round close date.