Norwegian University
of Life Sciences

Master's Thesis 2024 30 ECTS
The Faculty of Environmental Sciences and Natural Resource Management
(MINA)

Time to Turbine: A comparative Study of Offshore Wind Project timelines and Policy Implications in Denmark, the UK and Taiwan

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Renewable Energy

Acknowledgements

This thesis marks the end of five years of dedicated study, starting with the three-year bachelors program in Renewable Energy and ending with the completion of a wonderful two-year master's program in Renewable Energy, all at NMBU.

I want to thank my mentor, Per Kristian Rørstad, whose guidance and support has been very helpful throughout this journey. His role as a sounding board has been instrumental in shaping the direction of this thesis.

I also want to extend my gratitude to Esgian, particularly Oliver Stephenson and Kasper Grytnes, for their exceptional collaboration -providing me with extensive data, and readily answering any questions that arose.

A special thank you goes to my husband Hayden Hubbard. Thank you for believing in me, for your endless encouragement. Your input has been invaluable, and I am so grateful for your counsel and for having a wonderful soundboard in you -especially when things got challenging. I am also super grateful for your proof-reading of this thesis, as your language is more articulate than mine.

Lastly, I extend a heartfelt thanks to my extended family for their unwavering support and encouragement throughout this academic pursuit. Their dedication to fostering a conducive environment for my studies has been pivotal in enabling me to focus and dedicate myself fully to this thesis over the past four months.

The completion of this thesis would not have been possible without the support and encouragement of these individuals, and for that, I am eternally grateful.

Jørpeland, 20.04.2024

Annett Andersen Hubbard

Abstract

Until recently, the offshore wind industry has primarily operated within western markets. However, to achieve global climate objectives, technologies that mitigate carbon footprints, such as offshore wind, must be swiftly and extensively adopted. Recognizing this imperative, the World Bank initiated an effort in 2019 to assist emerging markets in identifying their offshore wind potential, laying the groundwork for the establishment of a robust offshore wind sector. While established markets have undergone a learning curve, often causing considerable expenses and delays, to streamline their offshore wind operations, many emerging economies may not have the same resources available. Hence, it is important to understand and analyze the policies implemented at different stages of offshore wind development and their impacts. This thesis aims to fulfill this objective by examining the historical trajectories and current policies of offshore wind sectors in Denmark, the UK, and Taiwan. Subsequently, it conducts a time distribution analysis to identify bottlenecks in leasing and construction processes, pinpointing areas where policies contribute to either acceleration or delays. Drawing mainly from data provided by Esgian, a specialized offshore installations data company, this study aims to offer insights for emerging markets to learn from the experiences of established ones, enabling the establishment of more effective country policies. At the same time, it provides Denmark, the UK and Taiwan with valuable insights into optimizing their offshore wind policies by addressing the identified inefficiencies in various phases of the process.

Sammendrag

Frem til nå har havvind vært en industri som hovedsakelig har vært forbeholdt vestlige markeder. For å nå globale klimamål må teknologier som reduserer karbonfotavtrykk, som for eksempel ulike former for havvind, implementeres på et globalt nivå på en raskt og effektiv måte. For å støtte opp om dette startet Verdensbanken i 2019 et initiativ for å hjelpe voksende markeder og land i utvikling med å kartlegge landenes vindressurser, noe som er essensielt for å bygge en robust havvind-industri. Mange av de etablerte markedene har gått gjennom en læringskurve med prøving og feiling, noe som ofte har ført til både betydelige utgifter og forsinkelser. Mange av de voksende markedene har trolig ikke ressursene som kreves for å gå gjennom en slik læringsprosess -og verdenssamfunnet har heller ikke tid til det dersom vi skal nå klimamålene som er satt. Av den grunn er det viktig å analysere ulike policyer og å forstå effekten de har på de ulike fasene i utbyggingen av havvind. Denne oppgaven har som mål å bidra til å øke forståelsen på dette området ved å se på den historiske utviklingen og det gjeldende rammeverket for havvind i Danmark, Storbritannia og i Taiwan. Dette vil bli etterfulgt av tidsbaserte læringskurver for budrunder for havvind, samt en analyse av tidsbruk fra budrunde starter til vindparken(e) er i drift, for bedre kunne identifisere flaskehalser i tildelings- og byggeprosessen. Dette vil videre gjøre det mulig å identifisere områder hvor politikken og de politiske prosessene bidrar til enten akselerasjon eller forsinkelser. Med data som hovedsakelig er hentet fra Esgian, et firma som spesialiserer seg på data for alle slags offshore installasjoner, vil denne oppgaven gi innsikt og forståelse til fremvoksende markeder -basert på erfaringen fra etablerte markeder, om hvordan de kan utforme sin politikk og sine politiske prosesser for å kunne bygge ut en havvindindustri på raskest og mest mulig effektiv måte. Samtidig gir oppgaven Danmark, Storbritannia og Taiwan verdifull innsikt i hvordan de kan optimalisere sine respektive policyer rundt havvind ved å identifisere og adressere ulike flaskehalser i hvert lands system.

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Abbreviations

AfL: Agreement for Lease

BESS: British Energy Security Strategy

CfD: Contract for Difference

CO2: Carbon Dioxide

DEA: the Danish Energy Agency

DIP: Demonstration Incentive Program

EIA: Environmental Impact Assessment

EPA: Environmental Protection Administration in Taiwan

EU: European Union

FiT: Feed-in-Tariffs

GHG: Green House Gasses

GW: Gigawatts

GWEC: Global Wind Energy Council

HSE: Health, Safety and Environment

HRA: Habitat Regulations Assessment

IDA: Industrial Development Administration in Taiwan

IRENA: International Renewable Energy Agency

ITT: Invitation to Tender

kWh: kilowatt hour

LCR: Local Content Requirement

LR: Learning Rate

MLOC: Maximum Level of Cash

MMO: Marine Management Organization

MOEA: Ministry of Economic Affairs in Taiwan

MOEAEA: Ministry of Economic Affairs, Energy Administration in Taiwan.

MW: Megawatt

MWh: Megawatt hour

NDC: Nationally Determined Contribution

NFFO: Non-Fossil Fuel Obligation

NGO: Non-Government Organization

NSIP: Nationally Significant Infrastructure Project

PDA: Project Development Area

PINS: Planning Inspectorate for England and Wales

PQQ: Pre-Qualification Questionnaire

RE Act: Danish Renewable Energy Promotion Act

ROC: Renewable Obligation Certificate

SEA: Strategic Environmental Assessment

TCE: The Crown Estate. Regulatory body in the UK.

UK: United Kingdom

ZAP: Zone Application for Planning by Taiwanese government

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1. Introduction

1.1. Background

Over the past few years, offshore wind has become a popular way for governments around the world to produce green energy (Hohl, 2022) and show that they are working to reach international agreements to reduce GHG emissions. This can e.g. be seen in the European annual and cumulative installed capacity, as well as in the expectant increase of installed capacity per year across European countries, as demonstrated by Ramírez et al. in Figures 1 and 2.

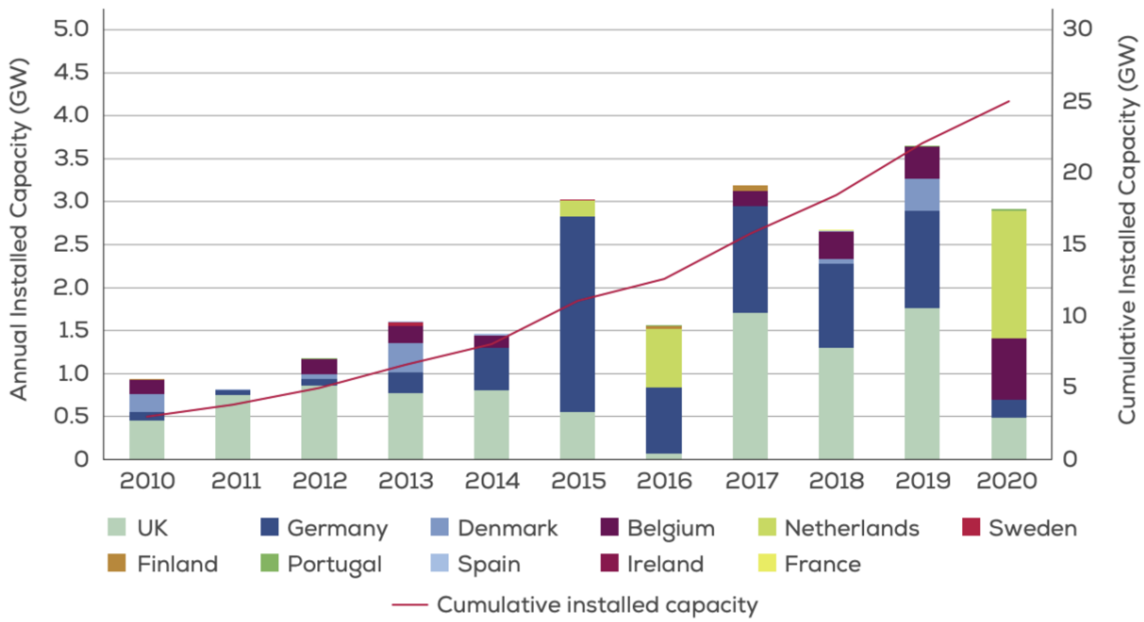


Figure 1 European annual and cumulative offshore wind installations by country from 2010 to 2020 (Ramírez et al., 2021).

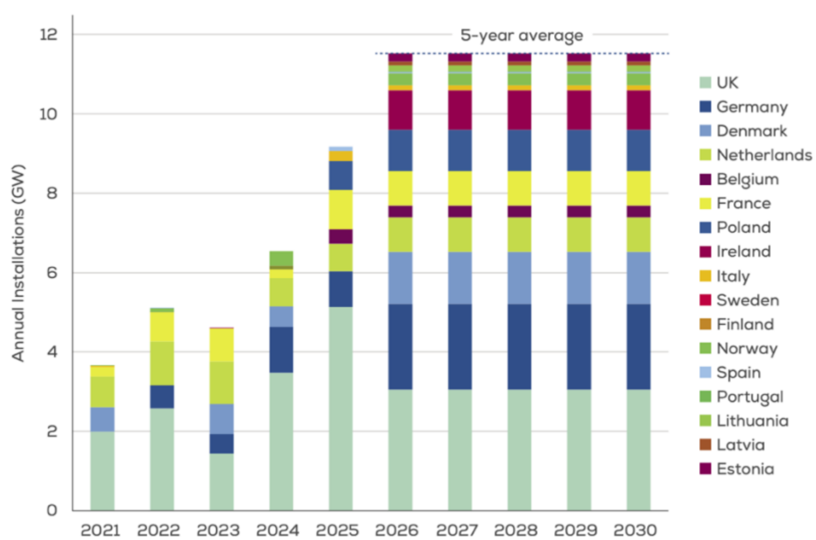


Figure 2. Expected annual installation of Offshore Wind capacity per country per year in Europe until 2030 (Ramírez et al., 2021).

However, from a commercial point of view, time is money and time spent building is lost revenue from power that could have been produced and sold. As more and more windfarms are designed and turbines are installed, it is assumed that the efficiency of the involved actors improves as they get more familiar with the processes and get better knowledge of technologies and markets. By studying the learning curve of the processes, one may more easily identify feasibility and the viability of a project. Additionally, one may get information on where the process is being slowed down and put in measures to speed it up.

According to IRENA and GWEC (2023), the world needs an installed capacity of nearly 500 GW offshore wind by 2030 if they are to achieve the 1.5°C scenario outlined in both the Paris Agreement and the Glasgow Climate Pact. By 2050, the need for installed offshore wind capacity will have risen to 2 465 GW. In 2020, the global installed capacity was about 35 GW (IRENA, n.d.). Further, many countries are struggling to reach their Nationally Determined Contributions (NDC), meaning they are struggling to reach the climate goals they have pledged to, and to reduce the amount of GHGs they have committed to the international community to abate (Tso, 2021). Most of the offshore wind farms that are announced today are set to start operation in 2030 -likely to help the host countries reach their NDCs and be on track with their emission reductions according to the Paris agreement or other international agreements. However, considering that wind farms are getting larger and larger over time, as seen in figure 3, and that the Dodger bank Wind farm outside of the UK, which will be the worlds largest offshore wind farm upon completion, had its license round opened in 2008 (Dodger bank wind farm, n.d.), started exporting energy in 2023 and is not expectant to be fully operational until 2026 (Equinor, 2023), it is unrealistic that the market will be able to construct and install such large amounts of capacity in such a short time.

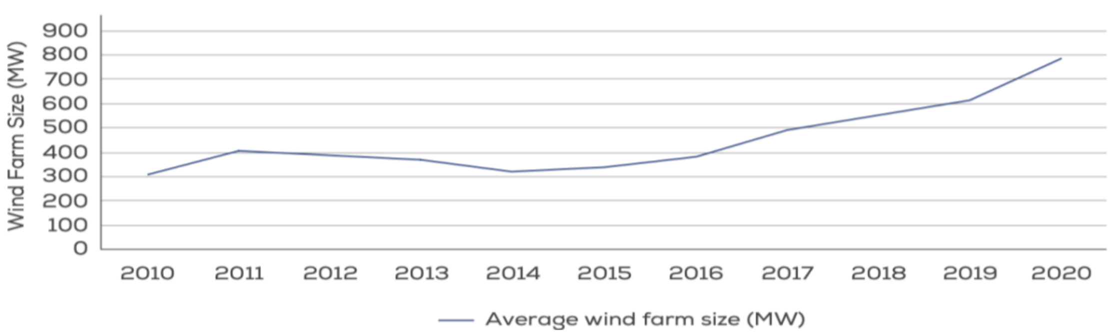


Figure 3. Average size in MW of commercial offshore wind farms per year (Ramirez et al., 2021).

In 2019 the World Bank started a 5-year initiative to help emerging markets integrate offshore wind to their respective countries policies and energy mixes (World Bank, n.d.). The program focuses on developing both policies and strategies to ensure good implementation, as well as helping each country map out their offshore wind resources and thereby find suitable areas. According to Oliver Stephenson in Esgian (personal communication, October 2023), it typically takes 3-5 years from when such an initiative is completed until the first offshore wind areas are put up for auction on the public market. Further, Mr. Stephenson explained that most countries so far has not made a profit from the first [few] wind farm[s] built. So far, most of the offshore wind industry is located in Europe and China (World Bank, 2019), who all have the opportunity to make such investments. The countries the World Bank is working with do not have the same opportunity to invest and learn over time, and it is therefore crucial that their offshore wind industry becomes profitable and as financially sustainable as quick as possible. In other words, there are about 10 countries expected to enter the offshore wind realm within the next few years, where neither country can afford to invest in experience. By studying the time-based learning curves and learning from how Denmark's, the UKs and Taiwan's policies affect the speed of the leasing and construction processes, these countries can hopefully gain a greater insight as to how to shape their policies as well as providing more accurate time estimates for completion and help make the processes smoother.

When choosing which countries to include in the analysis, there were a few factors that were important: It could not be a country with widespread corruption, the countries needed to have multiple offshore wind farms built, and they should preferably not be too similar politically. The UK was chosen as it has the second largest offshore windfarm portfolio in the world, after China (Fernández, 2023). Taiwan was chosen as it is located on a different continent, and because it has several new offshore wind projects. Hopefully, some of Chinas experience and policy has also inspired Taiwanese policy. Denmark was chosen because of its pioneering work in offshore wind, with the worlds first offshore wind turbine being installed in Danish waters in the early 1990s (de Vasconcelos et al, 2022).

1.2. Research Questions

"A learning curve can be defined as a graphical representation of the gain of proficiency or expertise in a domain over the time invested" (Shrestha, 2022). As of today, there has not been done much research on either time-based learning curves, nor how this time is split between the different phases from the start of a leasing round to when windfarms start operation. Such learning curves and insight into time distribution and development could provide insight to inefficiencies and identify bottlenecks, which further can lead to improved project planning and execution. By identifying and addressing potential risks in the logistics of a project or in the unique environment of a region, project managers may better address and mitigate potential risks. Learning curves and studying the development of timelines can help provide more accurate time estimates and better project planning, resulting in smoother project execution. Lastly, the information available from a time-based analysis can be of great support to politicians as they shape policies, such as subsidies or regulatory framework, that fosters the growth of offshore wind.

This thesis starts by examining the historic development and the current tendering systems in Denmark, the UK and Taiwan. Following that, it will look at time-based learning curves for the leasing process as well as how much time is spent on the different phases of developing a windfarm. In the discussion section, these analyses will be combined to create a picture of how they correlate and influence each other. The research questions for this thesis will be:

- How long does it take from announcing an offshore wind project, until someone has won the bid until construction starts and until the windfarm is producing in the 3 countries?
- Which processes or phases are slowing the project down the most?
- Are there significant differences between the countries?
    - If yes, why?
- How can emerging markets learn from Denmark's, the UKs and Taiwan's experience?

One of the main goals of studying timelines and learning curves is to help emerging markets know how to shape their policy around offshore wind so that they can 1. Meet their NDCs and 2. Develop and implement a successful offshore wind industry as fast and seamless as possible - without much of the starting cost that comes from gaining experience.

1.3. Scope

This thesis will focus on the impact of policy. This will be done by looking at the differences in award times for offshore wind projects in Denmark, the UK and Taiwan. More specifically, I will generate and compare learning curves associated with award times, and further compare and consider how the countries different policies influence these curves.

Following this, I will generate average timelines for building a new windfarm across said countries. Unlike with award times, which are presumably directly correlated to a country's policy, I will not be using learning curves for this analysis, as technological development and learning from implementation occur globally rather than domestically. I will compare the policies implemented in different countries with the timelines generated, with the goal of identifying learning outcomes that can guide emerging markets in implementing effective offshore wind strategies that can facilitating a smoother development process for the offshore wind industry.

2. Methodology

This thesis will be using a mixed-methods approach to investigate the policy frameworks and historical development of offshore wind projects in Denmark, the UK, and Taiwan, with the aim of providing recommendations for emerging markets to expedite the establishment of their offshore wind industries. The methodology is divided into two main phases: a review of each country's policy framework and data analysis.

The Policy Framework mostly consists of a literature review, which involves gathering and analyzing existing research papers, government documents, and industry reports related to offshore wind policies and development in Denmark, the UK, and Taiwan. This includes examining the regulatory frameworks, incentives, and challenges faced by each country in promoting offshore wind energy. I have also had a few meetings with Oliver Stephenson in Esgian that has given me further and detailed insight into each country's system and history. By synthesizing information from multiple sources, this phase aims to provide a comprehensive understanding of the policy landscape and its impact on offshore wind deployment.

Data for this thesis has mostly been given by Esgian, a company specializing in offshore data and analytics. Esgian has provided me with timeline data on every leasing round and every windfarm project that either is a concept still, has been decommissioned, or is somewhere in between those two phases in Denmark, the UK, and Taiwan. Some of the data relating to Denmark's Open-Door policy, which until recently has let the developers themselves find and initiate the development of an offshore windfarm (Lillebælt Syd, n.d.), as well as data for multiple demo projects have been challenging to find and may therefore in a few cases be lacking. Measures, such as either excluding them from an analysis or giving them the average time based off of similar projects have been taken in order to account for this. The datasets from Esgian have been used to generate learning curves to assess the relationship between the time spent awarding each MW of capacity and the total awarded capacity in each country. Additionally, the data is used to analyze the average time distribution for different phases of the leasing and construction process in the three countries.

"A learning curve depicts the relationship between [time] of a unit produced and number of units produced and is a good indicator of the [policy] development" (Aasbøe, 2021). The learning curve analysis aims to identify how much faster one may expect the leasing process to go as more capacity is awarded and each individual country gains experience. The learning curves will only be generated for leasing rounds, as generating them for the entire process would introduce systematic errors as developers develop and construct windfarms in more than one country. If such learning curves were to be developed, they would therefore need a global, and not a domestic scope (T, Martinsen, personal communication, February 2024). The objective is to look at the historic development and understand which countries are successfully learning from and improving their processes. Emerging markets can then learn which policies make processes faster and which ones do not.

Usually when talking about learning curves, it refers to reduction in prices. According to Martinsen (2010), the learning curve is generally described by the function:

$$C(X) = C_0 \cdot (X)^{-E} \quad \textbf{(1)}$$

Where C (X) is the cost of unit X,

C_0 is the cost of the first unit,

X is the number of units produced,

And E is the experience parameter.

However, this thesis will not be looking at cost, but rather at time spent. The function will therefore be altered to be:

$$T(X) = T_0 \cdot (X)^{-E} \quad \textbf{(2)}$$

Where T(X) is the time spent to build windfarm X,

T_0 is the time spent building the first windfarm,

X is the total installed capacity in each country,

And E is the experience parameter.

As described by Kutner et al. (2005), improvements in efficiency slow down over time, and the processes stabilize. To account for this, a logarithmic scale is often used so that linear regression can be applied. However, for the analysis in this thesis, the learning curves will be made in excel, as taught in Martinsens class FORNY360, where excels power regression is applied to the log-log transformed data. Power regression is a non-linear regression model based on the equation:

$$y = \alpha x^{\beta} \quad \textbf{(3)}$$

Where each component directly translates as a component from equation (2) in the following way:

$y = T(X)$

$\alpha = T_0$

$x = X$

and $\beta = -E$

Zaiontz (n.d.) shows that this can be done, and will give the same result as with linear regression, because when the natural logarithm is applied to equation (3), we get the following equivalent equation:

$$\ln y = \ln \alpha + \beta \ln x \quad \textbf{(4)}$$

Which can be translated to a normal linear regression model as displayed (with an added error term) in equation (5):

$$y = \alpha + \beta x + \varepsilon \quad \textbf{(5)}$$

Further, R^2 will be used to see how well the learning curve explain, or fit, the data. R^2 is the most commonly used "goodness-of-fit" variable, referring to variables used to determine how well a model fits and explains the data (Frost, n.d.) . It indicates the percentage of variance in the dependent variable (time spent per MW, in this thesis) that can be explained by the independent variable (total awarded capacity in MW in this thesis) -all done on a practical 0-1 scale (Frost, n.d.). In other words, when R^2 is closer to 1, the learning curve will usually capture the relationship between the cumulative country experience and the time spend developing a wind farm better. However, there are some limitations to this as explained by Frost (n.d.). If the residuals, meaning the distance between the observed value and the trendline, are large, the R^2 will be low indicating a poor fit. This does not necessarily have to be the case -it could simply be a wide range in the data and the trendline is still a good predictor for the future development. A more holistic approach should therefore be taken. One way of doing this is by looking at the residuals. If they are randomized, and stay somewhat consistently around the zero-line, the plot may still be good (Frost, n.d.; Taylor, n.d.).

Under the assumption that learning curves with a high R^2 explain the variation in the data well, I will in this thesis first try to correct the data for expected outliers if the R^2 is low. Frost (n.d.) explains that for studies that involve humans and their behavior, which governments awarding seabed leases arguably does, the R^2 will often be under 0.5 without it meaning that it is a bad model. Following Frosts argument, I will consider a low $R^2 < 0.5$. If the R^2 is low and does not improve when corrected for expected outliers, I will plot the residuals to assess whether the model could still be a good one before proceeding with any analysis.

It is important to note that although the learning curves are presented on a logarithmic scale, both the equation and the R^2 value are derived from the original, unaltered variables. This renders the R^2 a pseudo-R^2, which, as Kutner et al. (2005) explains, is an approximate measure and therefore subject to a slightly reduced level of accuracy. Nevertheless, given that my focus is on the generation of learning curves rather than an in-depth statistical analysis, this approximation of R^2 will suffice for the purposes of this thesis.

From the learning curves where R^2 is above 0.5, or the residuals indicate that the learning curve is still good, the Learning Rate (LR) will be calculated. This is done using the formula:

$$LR = 1 - 2^{-E} \quad \textbf{(6)}$$

The LR indicates how much faster in percent the tendering process is expected to go, as the total awarded capacity in the given country increases. When comparing the learning curves of different countries, one may gain a better understanding of the efficiency within each country. If the LR is high, the processes in offshore wind industry is likely to be adaptable and quickly improving. However, if the LR is low, the opposite is true.

The time distribution analysis examines historical data and expected development trends in the three countries to identify which phases of the leasing and construction process are taking the longest. The time distribution will be presented in stacked bar charts that show the total time spent per MW, where each bar is split into: the time spent on the leasing round, from when the leasing round ends to the leases are awarded, from when the leases are awarded until the construction starts with the installation of foundations, from the installation of foundations start until the installation of turbines start, and lastly from the installation of turbines start until the windfarm is fully operating. For an illustrated overview, see figure 4. This analysis helps pinpoint bottlenecks and inefficiencies that may be addressed through policy interventions or process improvements.

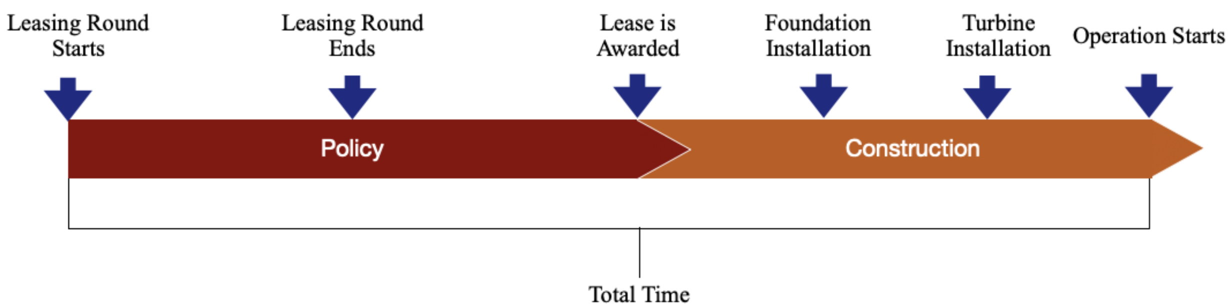


Figure 4 Different phases that will be analyzed in the time distribution section.

The findings from the data analysis, meaning the learning curves and the time distribution analysis, are compared with the findings in the literature review to identify discrepancies or correlations between policy frameworks and project timelines. This comparative analysis aims to uncover potential policy levers or stumbling blocks that could either accelerate or halter offshore wind development in emerging markets.

3. Policy Framework

This section consists of a literature review for each country. Several articles and papers are used to generate a comprehensive idea of what the historic context, the current tendering process as well as central incentive mechanisms in Denmark, the UK and Taiwan are.

3.1. Denmark

3.1.1. Historic context and plans moving forward

Denmark is a pioneer within the offshore wind realm -seeing that the world's first offshore wind farm was built in Danish waters in 1991 (de Vasconcelos et al, 2022). In the mid 80s, the Danish government obligated the public utility companies Elkraft and Elsam to install Offshore Wind Power without subsidies through the "100 MW Agreement" (Rentier et al., 2023). The agreement meant that these public companies would build the windfarms the government requested, in exchange for a less permissive policy towards private investors in wind energy (Rentier et al, 2023). Multiple of these, or similar agreements were made in the following years, sometimes with a "technology-specific guaranteed market price" (Rentier et al., 2023). However, not all the planned windfarms ended up being built. Such practices have later been suspended due to being in violation of EU-laws and regulations made to ensure open markets.

In 2001, following an election and a government change, Denmark's offshore wind strategy was paused and became a topic of discussion. A more liberal-conservative government wanted a more competitive policy and started airing the idea of international companies being able to bid on offshore wind auctions. This created uncertainty around policy. According to Rentier et al (2023), the shift from directly negotiated government-utility deals to competitive auctions took several years of discussion. Even if the government agreed on international auctions in 2004, political harmony was not restored until 2012 when the “Energy Agreement” received a 95% approval and introduced the goal of having 50% of electricity in Denmark come from wind power (Rentier et al., 2023). There were now two ways of getting approval to build an offshore wind farm; through open auctions or through the “open-door policy” -where the latter in many ways can be seen as an extension of the original policy. Under the “open-door policy” the developer finds an area to establish a wind farm, and then applies for permission to carry out all necessary preliminary research. The application and their findings would then be submitted to the Danish Energy Agency (DEA), who would review everything and give permission to proceed. There were three permits necessary to establish a windfarm this way, and they were given as the project progressed. The permits were in other words conditional upon the previous permit. The necessary permits were: permit to preliminary investigation, permit to establish a windfarm and a permit to produce and sell energy (Lillebælt Syd, n.d.). Before a project would be given the first permit, meaning the permit to preliminary investigation, the DEA sends the application on a public hearing to make sure there are no conflicting interests. After the preliminary investigation was completed, an environmental impact assessment had to be submitted to the DEA who would do quality assurance and then send it on another hearing among relevant public instances. Before a project would be given the permit to construct, there would be a public hearing where anyone interested could come and voice their concerns or their opinions (Lillebælt Syd, n.d.).

Another Energy Agreement came in 2018 and stated that Danish electricity consumption will be covered by renewable energy by 2030, and 55% of this energy should come from offshore wind (de Vasconcelos et al., 2022). To my knowledge, this goal is still standing. However, it may prove to be challenging as many projects were given permission through the aforementioned “open-door” policy. The open-door policy operated under the first come first serve principle, which the EU deemed incompatible with its laws and policies regarding open and competitive markets. As of first quarter 2023, the DEA closed the open-door policy and suspended a series of projects that had been granted leasing and building permits for offshore wind in Danish waters (Energistyrelsen, 2023). What the future holds for these projects is currently unknown, but the industry assumption is that many or most of these areas will be put up for public auctions in the coming years, but this is not officially confirmed yet (O, Stephenson, personal communication, January 2024).

3.1.2. The leasing process

The right to exploit wind energy from Danish territorial waters and in their Economic Exclusive Zone are coordinated by the DEA under the 2015 Danish Renewable Energy Promotion Act (RE Act), in corporation with the Danish Environmental Protection Agency, the Danish Maritime Authority and the Danish Working Environment Authority (de Vasconcelos et al., 2022). Under the RE Act of 2015, the DEA must grant three key permits:

1. License to execute a preliminary investigation
2. License to build or construct the windfarm
3. License to produce energy

To make the process easier, the DEA functions as a “one-stop-shop”, and is the only regulatory body any developer needs to communicate and work with (DEA, 2020). De Vasconcelos et al. (2022) explains that the areas for offshore wind are identified by a committee in the spatial planning process. This committee consists of members from the DEA, Danish Nature Agency, Danish Maritime Authority, the Danish Transmission System Operator (Energinet) and Denmark Technical University -Risø. The committee makes an environmental impact assessment, which during the public tendering process in Denmark is done before any offers are submitted. The public then gets to voice their concerns or come with any inputs before the areas move towards public bidding.

Next, the DEA announces the size and location of the windfarms. To ensure that only reliable project developers are invited to submit tenders, the DEA conducts a pre-qualification of the potential bidders by evaluating a number of minimum requirements regarding the financial, economic and technical strengths of the applicants (DEA, 2022). Those who pre-qualify are invited to submit their production price. This should be submitted as amount of Danish øre/kWh and is the price the applicants would need to sell their electricity for in order to want to build the windfarm. The applicant should also state the size of the windfarm along with an estimate of full-load hours of production per year (DEA, 2021; de Vasconcelos et al., 2022). After the tendering process, the DEA will announce the winning bid and enter into a concession agreement with the winner. The outline of the whole process can be seen below in Figure 5.

Figure 5 The tendering process Denmark (de Vasconcelos et al, 2022).

3.1.3. Other policies and incentives for Offshore Wind

Offshore wind energy development in Denmark has seen multiple strategic incentives with the goal of growing and increasing both investment, innovation, and sustainability. As a pioneer in the sector, Denmark has continuously evolved its incentive framework to adapt to changing market dynamics and policy priorities.

One of the key mechanisms employed by Denmark is the use of FiTs (de Vasconcelos et al., 2022). Through FiTs, developers are offered a guaranteed price for the electricity generated from offshore wind farms. This provides financial certainty and reduces investment risks, thereby incentivizing developers to invest in offshore wind projects. By offering a fixed price for electricity, FiTs have helped create stability and attract more investors that further contributes to growing the Danish Offshore Wind industry.

In addition to FiTs, Denmark is also embracing competitive auctions as a means of promoting cost-efficiency and driving down the price of offshore wind energy (de Vasconcelos et al., 2022). By allowing developers to compete for project contracts, auctions encourage innovation and cost optimization -ultimately benefiting consumers by lowering electricity prices and creating favorability for the industry among them.

Further, Denmark has demonstrated a commitment to long-term policy stability and ambitious renewable energy targets. Clear targets, such as covering electricity consumption with renewables by 2030 and achieving independence from coal, oil, and gas by 2050 (de Vasconcelos et al., 2022; Rentier et al., 2023), provide investors and developers with a clear prospect and stable projections for the Danish Offshore Wind industry. This further attracts investment and foster both industry growth and innovation.

According to Erraia et al. (2023), the Danish Government rolled out the use of a two-sided Contracts for Difference (CfD) in relation to the construction of the windfarm Thor, whose lease was awarded in December 2021 and will be Denmark's largest windfarm upon completion. The use of CfD is expected to create a stable settlement price for power generated by the windfarm. The winning bidder was awarded a 20-year contract, and the strike price will be adjusted annually to keep up with changes in the electricity prices. The strike price was set at a EUR 0.01 revenue per MWh, and the generator pays back the difference between the market price and the strike price until the agreed cap of EUR 372 million is met (Erraia, 2023). Jansen et al (2022) further explains that CfDs have recently increased in duration from 12 years to now being 20 years. This provides financial certainty and improves different projects viability for developers. Additionally, it aligns Denmark more with policies of other markets or countries -which again makes them a more attractive market to invest in. Jansen et al. (2022) also outlines how projects face penalties if they fail to live up to their end of the contract or deliver on time. This penalty includes both lump-sum penalties as well as reduction in support.

Denmark's combination of incentives, including FiTs, competitive auctions, policy stability, penalties on failed agreements, and recently also CfDs, have been instrumental in making offshore wind an attractive industry and creating growth.

3.2. The UK

The UK's offshore wind sector, which is one of the world's largest, is positioned for substantial growth, with a goal of having 40 GW installed capacity by 2030 (de Vasconcelos et al., 2022). This ambitious target aligns with the 2008 Climate Change Act, which mandates a 34% reduction in greenhouse gas emissions by 2020 and the UK's commitment to net-zero emissions by 2050 (GWEC, 2021).

3.2.1. Historic context and plans moving forward

The historical trajectory of offshore wind policy in the UK is characterized by a series of strategic developments and policy instruments over many years. The liberalization of the electricity supply industry started fairly early with the Electricity Act of 1989. This led to multiple companies being created and the private market accommodating to the UKs policy. By 2012, 10 generation companies, owning almost 86% of UK generation assets had emerged, likely as a result of the 1989 Electricity Act (Rentier et al., 2023). The Non-Fossil Fuel Obligation (NFFO) was part of the 1989 Electricity Act and introduced a quota obligation scheme and competitive auctions to support non-fossil electricity production. According to Rentier et al. (2023), the legislation first obligated electricity suppliers to buy all electricity from nuclear and renewable that producers offered the market. Then, they awarded contracts to companies that would develop non-fossil electricity production with the least subsidies.

The utility act of 2000 further incentivized and increased demand for renewable energy through the introduction of Renewable Obligation Certificates (ROC). It obligated suppliers to ensure that a given volume of their electricity supply came from renewables. This was done through tradeable certificates for renewable generation. The minimum quota increased steadily from 3% in 2002 to over 10% in 2010 (Rentier et al., 2023).

Following the financial crisis in 2008, UK investments in Offshore Wind stalled (Rentier et al., 2023). As technology developed and wind farms were built on deeper waters further from the shore, the government introduced the Green Investment Bank in 2012 to help finance many of the bigger upcoming projects. This helped facilitate further growth. In 2013, the UK's government also introduced CfDs, to share the price risk between firms and the government. It was first taken into use in 2015, and between 2015 and 2017 bid prices during offshore wind auctions halved, suggesting that the policy has been highly effective (Rentier et al., 2023).

3.2.2. The leasing process

In the UK, the leasing process is characterized by a well-defined and comprehensive framework to ensure sustainable and responsible development. All offshore wind leases are awarded through public auctions. However, the regulatory landscape involves multiple jurisdictions, with The Crown Estate (TCE) managing exploitation rights for wind, waves, and tides on the continental shelf in England, Wales, and Northern Ireland, while The Crown Estate Scotland oversees the

Scottish seabed. The licensing process is built on key legislations such as the Electricity Act of 1989, the Planning Act 2008, the Marine and Coastal Access Act 2009, and the Marine (Scotland) Act 2010 (de Vasconcelos et al., 2022).

According to de Vasconcelos et al. (2022), the environmental licensing process in the UK varies depending on the jurisdiction. In England and Wales, the Marine Management Organization (MMO) is responsible for consenting offshore energy projects between 1 and 100 MW, while projects exceeding 100 MW are classified as Nationally Significant Infrastructure Projects (NSIP) and processed by the Planning Inspectorate for England and Wales (PINS). Offshore wind projects need Environmental Impact Assessments (EIA) unless granted an exemption from a relevant authority, such as the Secretary of state in England (White & Case, 2019). There aren't any exemption criteria stated by the UK government, so any such exemption would happen on a case-by-case basis. The EIA should evaluate all potential environmental impacts throughout the project's lifecycle.

As seen in figures 6 and 7, the leasing procedure is slightly different in the UK and in Scotland. The process described for the UK is based on the guidelines for leasing round 4, which was the latest completed leasing round in the UK as per January 2024. In the first quarter of 2024, information about tendering in the Celtic Sea has been published. The areas in the Celtic Sea is expected to be awarded in September 2025. Leasing round 5 has a very similar leasing process, but the Habitat Regulations Assessment (HRA), that "assess the possible impact of the awarded projects on relevant nature conservation sites of European importance" (TCE, 2019), seems to be playing a lesser part than it did in leasing round 4. However, as leasing round 4 is the last leasing round completed, this analysis will be based off that.

In the UK, the leasing round starts with a Pre-Qualification Questionnaire (PQQ) that potential bidders need to fill out and pass to qualify for the tendering process. The questionnaire focuses on the bidders' technical experience, financial standings and legal compliance. The PQQ also outlines the key components of the legal agreement that will be entered into when developing the areas awarded in the leasing round.

According to TCE (2023), those who submit a successful PQQ, move on to the next round - meaning the Invitation to Tender Stage 1 (ITT Stage 1). During ITT Stage 1, bidders will be evaluated based on their ability to develop the area in a desired way. This includes looking bidders' technical capabilities and their adherence to health, safety, and environmental (HSE) standards necessary for successful project execution within any of the specified Project Development Areas (PDAs). Additionally, bidders need to outline their strategies for integrating ports and their plans for creating social and environmental value throughout the duration of the Legal Agreements. ITT Stage 1 will also determine the bidders Maximum Level of Cash (MLOC) available, which plays a big role for those who proceed to ITT Stage 2 (TCE, 2023). The MLOC is designed to ensure that a bidder can meet the minimum expected future financial commitments required for a given development, and is calculated as 1.5 times the annual development cost. Bidders are required to demonstrate that they are financially capable of developing the windfarm they want to bid on. This is done by evaluating their Cash, Cash Equivalents and Undrawn Borrowing Facilities, as stated in the Bidder's most recent set of audited financial statements (TCE, 2023).

During ITT Stage 2, an auction takes place to determine the allocation of each PDA. The auction is a multi-cycle bidding process and proceeds until there is only one bidder willing to meet the auction price for each PDA in a given auction round. To participate in this stage, bidders must sign a Preferred Bidder Letter and pay an Option Fee Deposit (TCE, 2023; TCE 2019).

Further, the Crown Estate (TCE) will conduct a plan-level HRA of the winning bids. If the HRA is reasonable and approved by TCE, the parties will enter into an Agreement for Lease (AfL). If deemed necessary, TCE can make amendments to the draft Wind Farm AfL shared with Bidders at ITT Stage 1, to address the outcome of the HRA Conformity Check (TCE, 2023).

In Scotland, de Vasconcelos et al. (2022) explains that the Marine Scotland Licensing Operations Team issues marine licenses in a streamlined procedure. The consenting process in Scotland includes a comprehensive Sustainability Appraisal, which encompasses a Strategic Environmental Assessment (SEA), an HRA, and a Social and Economic Impact Assessment. The supply chain is also a crucial consideration, with developers required to submit a Supply Chain

Development Statement outlining the anticipated impact on the supply chain at different project stages. The entire process is designed to align with international and European conservation laws, emphasizing environmental responsibility and sustainable development. An overview of what recent the leasing procedure for “Scotwind round 1” looked like, where bidders were awarded the leases in January 2022, can be seen in figure 7.

Figure 6 The tendering process in the UK (de Vasconcelos et al., 2022).

Figure 7 The tendering process in Scotland (de Vasconcelos et al., 2022).

3.2.3. Other policies and incentives for Offshore Wind

The UK has implemented a range of incentives to make offshore wind more attractive and facilitate its rapid expansion. One significant incentive is the introduction of policy mechanisms such as the ROC and CfD (Rentier et al., 2023). Under the ROC system, renewable energy producers were awarded certificates for each MWh of electricity generated, which could then be traded in a market setting. This provided a stable revenue stream for renewable energy projects and encouraged investment by ensuring a guaranteed income. Similarly, the CfD mechanism operates by providing financial support to renewable energy developers through auctions, where the government sets a strike price for electricity generated from renewable sources. If the market price falls below the strike price, the government reimburses the difference, reducing financial risks for developers and incentivizing investment in offshore wind projects.

In addition to financial incentives, the UK government has also provided direct investment and grant funding to support offshore wind development. Initiatives such as the Offshore Wind Capital Grants Scheme allocated significant funding to offshore wind projects, providing grants to support their development and offsetting some of the initial capital costs (Rentier et al., 2023). Furthermore, the government's establishment of the Green Investment Bank, later privatized under Macquaire, provided a reliable co-investor and facilitated project financing, particularly for larger offshore wind projects that faced challenges in securing funding from traditional sources following the 2008 financial crisis (Rentier et al., 2023).

Moreover, the UK's licensing and regulatory framework is designed to streamline the development process and provide certainty for investors. The introduction of leasing rounds by TCE, coupled with robust EIAs and stakeholder consultations, creates a clear pathway for developers to secure offshore wind sites and navigate the consenting process effectively (de Vasconcelos et al., 2022). By offering a reliable regulatory framework along with financial incentives, the UK aims to attract investment, drive down costs, and accelerate the installation of offshore wind capacity.

The incentives mentioned above have worked well to ensure a willingness to invest in Offshore Wind in the UK. However, they have not necessarily contributed to R&D or industrial growth domestically. To combat this, the Offshore Wind Industrial Strategy was launched in 2013, with the goal of supporting both industrial growth and a cost reduction in offshore wind. The strategy set targets for domestic content and provided support for both diversification and for R&D (MacKinnon et al., 2019). According to MacKinnon et al. (2019), the incentive has only been partially effective, as the UK still relies heavily on multinational lead firms and imports for turbine manufacturing.

3.3. Taiwan

The Taiwanese development of Offshore wind is a relatively recent one. The country has become the second-largest offshore wind market in the Asia-Pacific region (de Vasconcelos et al., 2022). In general, international offshore developers and other companies are attracted by the governments FiT, good wind resources and the country's ambitious targets to adopt clean energy.

3.3.1. Historical context and plans moving forward.

The offshore wind industry in Taiwan, though in its early stages compared to Denmark and the UK, has witnessed significant growth and development in recent years. Much of this is likely due to the Energy Administration in the Ministry of Economic Affairs (MOEAEA) four-year plan for promotion of wind power. This has given the Taiwanese offshore wind industry a strategic framework -emphasizing phased approaches of demonstration, planning, and zonal development.

However, Offshore Wind has not always been easy sailing for Taiwan. In 2007, Taiwan announced its "Program for the First Stage of Offshore Wind Development," aiming to develop 300 MW of offshore wind capacity. Gao et al.(2021) explains that due to low power purchasing rates and insufficient policy support, this program failed to achieve its objectives. It wasn't until the Fukushima accident in 2011 that Taiwan's offshore wind policy gained momentum again. Under the New Energy Policy of 2011, Taiwan set ambitious targets for offshore wind deployment, with a plan to install four demonstration turbines by 2017 and 3 GW of capacity by 2025 (Gao et al., 2021).

Drawing insights from international experiences, Taiwan committed to their offshore wind journey, prioritizing demonstration projects, and initiated the Demonstration Incentive Program (DIP) in July 2012. The DIP awarded leases to three windfarms, with two being developed by the private sector (Formosa and Fuhai) and one by a state-owned company (Taipower) (MOEA, n.d.). As a milestone, the first operational windfarm started production in April 2017, followed by the two other windfarms in 2019 and 2021.

As seen by the misalignment in Taiwan's goals and the actual operation start dates, Taiwan faced both delays and cancellations in its offshore wind projects. Gao et al. (2021) explains that this included protests from fishermen, construction delays, and financial issues. In response to the challenges, policy adjustments were implemented, including the introduction of FiTs aimed at attracting developers. The FiT saw an increase in 2015, around the same time MOEAEA introduced the Directions of Zone Application for Planning. The FiT made Taiwan an appealing market for offshore wind investment, particularly as European markets experienced reduced FiTs (Gao et al., 2021). Additionally, to further facilitate offshore wind development, Taiwan implemented zoning regulations and strategic environmental assessments. The government sought to balance renewable energy deployment with industrial development. This was done by focusing on establishing a local supply chain for the offshore wind industry (Gao et al., 2021).

Along with the Directions of Zone Application for planning, 36 Zones of Potential were also introduced (MOEA, n.d.), offering a structured framework for developers to secure planning permission (de Vasconcelos et al., 2022). Notably, this marked Taiwan's first competitive price-based auction with no mandatory local content requirements (Ørsted, 2023). Instituting both a selection and bidding process for offshore wind power projects, the selection process concluded by April 30, 2018, allocating a capacity of 3,836 MW, followed by the completion of the bidding process on June 22, 2018, resulting in an additional allocated capacity of 1,664 MW (Song, 2023).

However, Taiwan encountered further challenges in the implementation of its offshore wind policies, including controversy over FiTs, delays in project approvals, and difficulties meeting local content requirements (LCRs). LCRs require a certain portion of a project's components or resources must be sourced locally. Political turmoil ensued, with accusations of high FiTs and a lack of rule of law (Gao et al., 2021). Despite these challenges, Taiwan will be exceeding its initial offshore wind target of 3 GW installed capacity by 2025 (de Vasconcelos et al., 2022). This is due to an over-subscription of projects proposed by developers, indicating that they (the developers) have remained committed to securing permits and contracts with the government.

LCRs have remained a challenge for many developers when trying to establish business in Taiwan, as there is a lack of necessary industry to support the construction of offshore wind farms. However, the LCR requirement has created efforts in establishing such an industry. Among other things, this has been done through training programs and investment in the local industries that already exist (Gao et al., 2021).

Formosa 2, a 376 MW windfarm which was awarded lease in April 2018, fueled Taiwan's momentum by starting production in September 2023. Currently, Formosa 2, along with the three windfarms awarded leases under the DIP, stand as Taiwan's sole operational entities as of January 2024. However, several others are under construction, anticipated to start operation by the end of 2024, with additional projects from the 5.5 GW awarded in the selection and bidding rounds expected to be operational by 2025.

Despite the challenges and controversies, Taiwan's offshore wind industry has made significant progress, positioning the country as a major player in the Asia-Pacific region and attracting international investment and expertise (de Vasconcelos et al., 2022). Looking ahead, MOEAEA and the Environmental Protection Administration are hoping to increase offshore wind development through marine spatial planning and aligning national resources with the installation of offshore wind power (MOEA, n.d.). This strategic approach aims not only to increase green power generation, but also to foster a resilient local supply chain. This will help Taiwan be independent in its power production, as well as move them towards, and their target of achieving 3 GW of installed capacity by 2025 (MOEA, n.d.).

3.3.2. The leasing process

The regulating power that oversees any leasing processes in Taiwan is the Energy Administration in the Ministry of Economic Affairs (MOEAEA). As mentioned in 3.3.1., the process leading up to this point has been slightly turbulent for Taiwan, but it does seem like they are out of the woods now and mostly working on building and regaining trust from the industry. Per January 2024, it seems like the leasing processes in Taiwan are starting to form a pattern of a two-step allocation process consisting of a qualification review and of a price auction (Baker & McKenzie, 2023).

The process begins with the Zone Application for Planning (ZAP), initiated by the Ministry of Economic Affairs (MOEA). Through this stage, the MOEAEA identifies and designates areas suitable for offshore wind farm development. Next, the EIA process must be completed. This is done through close collaboration with the Environmental Protection Administration (EPA) and other governmental bodies. Both the planning and EIA process is done by the government to save both time and cost, as well as aid in establishing local industry (de Vasconcelos et al., 2022).

According to Baker & McKenzie (2023), the MOEAEA will look at all applicants engineering designs, construction capabilities as well as their plans for operation and maintenance. They will also review applicants financial and risk management proposal and how financially sound the applicants' shareholders are. To be considered and pass to the next round, the applicants must receive a score of 70 or higher in MOEAEAs scoring system for the mentioned categories combined. Further, the Industrial Development Administration (IDA) under the MOEA sets requirements for use of local components and expertise. How this is being done has differed slightly between the different auction rounds, but overall, any applicant must be prepared and willing to procure a high percentage of local items and/or expertise to be able to participate in the price auction. For round 3.2, which will happen while this thesis is being written, the IDA has made a list of 24 different measures or items an applicant can use, and given each of the measures a score. The applicant may choose whichever items from the industry relevance items they want to implement, but as mentioned, they need a score of at least 70 points to be able to participate in the price auction. (Baker & McKenzie, 2023).

For those who satisfy all the requirements presented in the qualification review, the next step is to place bids for the grid allocation awards. The award is done based on bidding price, meaning the price they sell the electricity to Taipower (Taiwans state owned utility company) for. The bidding price must be between NTD 0/kWh and NTD 2.49/kWh. If two or more applicants happen to bid the same price, the applicant with the highest score on the assessment of use of local components and expertise will win (Baker & McKenzie, 2023).

Figure 8 The tendering process in Taiwan.

3.3.3. Taiwanese policies and incentives for Offshore Wind

Taiwan is an island with an independent energy system (Gao et al., 2021), and therefore have multiple reasons, ranging from energy security to public health to carbon reduction and international agreements, as to why they would want to make their energy production as clean and renewable as possible. In addition to that, MOEA assumably aims to stimulate and facilitate economic growth and the development of new industry. To align with this, there are multiple correlating policies and incentives connected to the offshore wind industry that may be helpful to be aware of.

First, the Taiwanese government has consistently included a Local Content Requirement (LCR) when awarding leases. The LCR has looked different in different rounds, and, based off the lack of consistency, it seems like they might not have settled for a final or best solution yet. However, by including this they are creating local business opportunities and incentives to develop competencies and foster growth that the industry is in much needed of. On the other side, the LCR has created growth barriers as international companies have struggled to find the necessary skills and competencies locally to meet the LCR. One could say this is shooting yourself in the leg, or one can look at it as investing in the Taiwanese future of wind energy -it all depends on whether you are expecting to see results fast or if you are playing the long game.

Second, Taiwan has had high Feed-in-Tariffs (FiTs) that has made wind power more profitable than it is in many other countries. Offshore wind requires a higher electricity price than other technologies to be profitable (IRENA, 2019). This creates a risk for the investors, that can be countered with high or good FiTs. However, Taiwan has also seen some challenges regarding public acceptance of Offshore Wind Power just because of the high FiTs (Gao et al., 2021). If the prices increase dramatically for consumers because they have to pay for the expensive power, they are likely to oppose the technology and rather see that another technology which can provide cheaper power is used first.

Though Taiwan has been criticized for a lack of consistency and investment security (Gao et al., 2021), the Taiwanese government have set and seem to be following through on their offshore wind installed capacity targets and plans (Song, 2023). This helps create trust and predictability. As more and more countries open areas for offshore wind, security and predictability are some factors that likely will become increasingly important when companies choose which countries to invest in (O, Stephenson, personal communication, October 2023).

3.4. Key differences

The three countries seem to be moving in the same direction when it comes to the tendering process -namely, public auctions. The UK has extended experience here, and Denmark has a fair amount of experience as well -though their main tendering method until recently has been the now-discontinued "open-door" policy. Taiwan started by awarding leases directly to companies but have now moved to public auctions and seem to be keeping that for future leasing rounds.

Likewise, in all countries, developers must be pre-qualified to participate in the public auctions. The pre-qualification in the countries is done to ensure that all bidders have the technical and financial capabilities to develop the windfarm(s) the way the government has envisioned. A difference here is that the UK seems to have a few more steps in their auctioning rounds, with ITT Stage 1 and 2, than what can be seen in Denmark with their one-stop-shop and in Taiwan.

Additionally, the countries rely on different incentive mechanisms. Taiwan mainly uses FiT to make Offshore Wind an attractive investment. Denmark was also built on FiTs, but seem to be moving towards CfDs in the latest leasing rounds. The UK has seen great success with CfDs as their main financial incentive over the last years. ROCs have also played a big role in the UK development of offshore wind. The main difference however, is that Taiwan has a pretty big focus on LCRs to build local industry, something that seems to be less of a priority in the other countries.

4. Efficiency and learning insights

For the learning curves generated in this section, the processing times, or the time it takes from the regulating instances opens a leasing round until it awards said lease, will be analyzed. For the time distribution, the entire timetable from a leasing round opens until the windfarm(s) are operating will be analyzed.

4.1. Denmark

The tendering and leasing process has until recently looked slightly different in Denmark because of its history with Open-Door policy. Even if the practice now is suspended on charges from the EU, it can still give a good indicator for emerging markets on whether this is a fast and efficient policy compared to that of the UK and that of Taiwan.

4.1.1. Policy Learning curve

For this section, all leasing rounds, will be included in the first analysis. Next, an analysis without the Open-Door rounds will be done. The hope is that differentiating the two will make a comparison with the other countries more meaningful later in section 5.2. There will also be a differentiation between the leasing rounds that have taken place, meaning the already awarded leases, and the expected development -which includes the upcoming leasing rounds that have been announced as of January 31st 2024. As Denmark has suspended a large amount of projects that got approval through the Open-Door policy, it is expected that these projects will become public bidding rounds somewhat soon (O, Stephenson, personal communication, January 2024), but since these have not been announced before January 31st 2024, they will not be included in this analysis. The projects included, with corresponding data, can be found in Appendix 1.

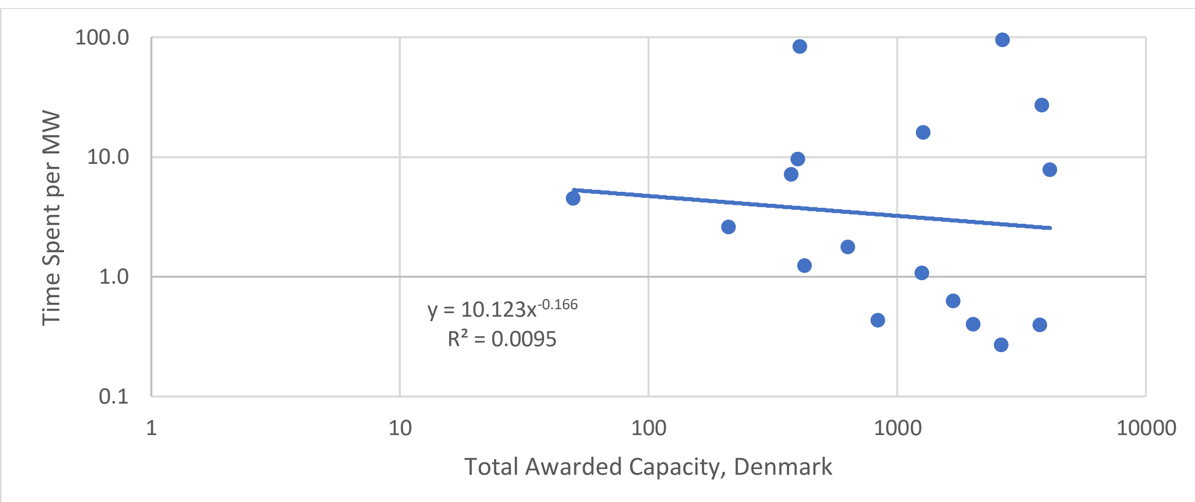


Figure 9 Learning Curve for all already awarded leases in Denmark.

The first learning curve to come out of these data can be seen in figure 9 and considers all leases that have been awarded so far. There is clearly very little pattern shown in the development. With an R^2 that is approaching 0, it is uncertain whether calculating a LR would be meaningfull. As mentioned earlier, “open-door” leases have been very common in Denmark historically. This can also be seen in Appendix 1, where a majority of the leases awarded before 2024 were awarded through the Open-Door policy. These may have created outliers that are polluting the data. Before moving to any other "goodness-of-fit" variables, let us try to remove the expected outliers. Figure 10 looks at what happens if the leases awarded through the "open-door" policy is removed:

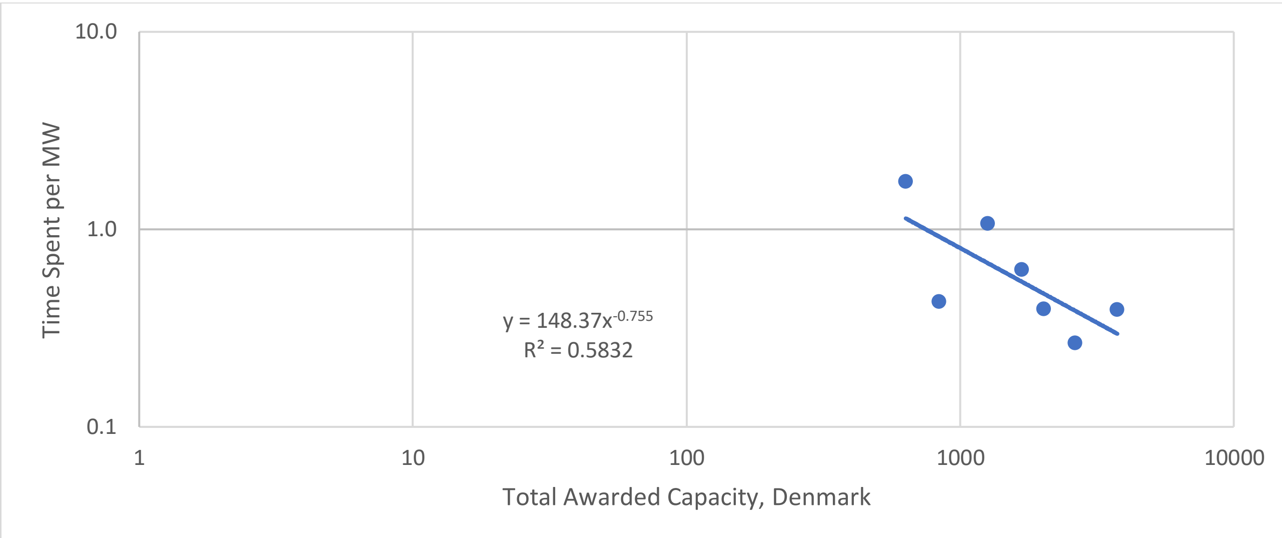


Figure 10 Learning curve for all already awarded leases, excluding open-door projects in Denmark.

The data pool has now clearly shrunk, but the R^2 has also increased substantially. It seems like the curve follows the data fairly well, even if the R^2 indicates that it can only account for 58% of the variation observed. That makes it more meaningful to also calculate and look at the LR, which in this case is calculated to be about 41%. This means that as the Awarded capacity in Denmark doubles, the time spent awarding each MW is expected to decrease with 41%.

As mentioned, many of the "open-door" leases have been suspended, and many public leasing rounds are scheduled to take place. By including these in the analyses, the learning curves for the expected development are produced in figures 10 and 11.

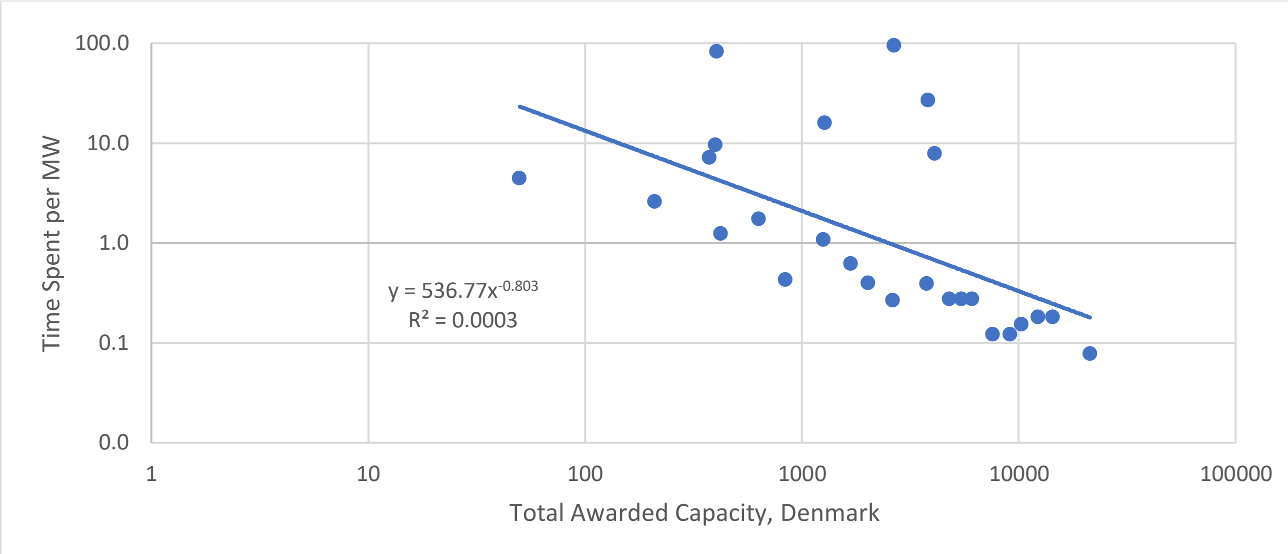


Figure 11 Learning curve for all leasing rounds in Denmark.

In figure 11, the learning curve for all past and all scheduled future leasing rounds is included. Again the R^2 comes out to be close to 0. As the R^2 improved so drastically when excluding "open-door" projects in Figure 10, let us see if this trend will keep up –especially as none of the future leasing rounds are "open-door".

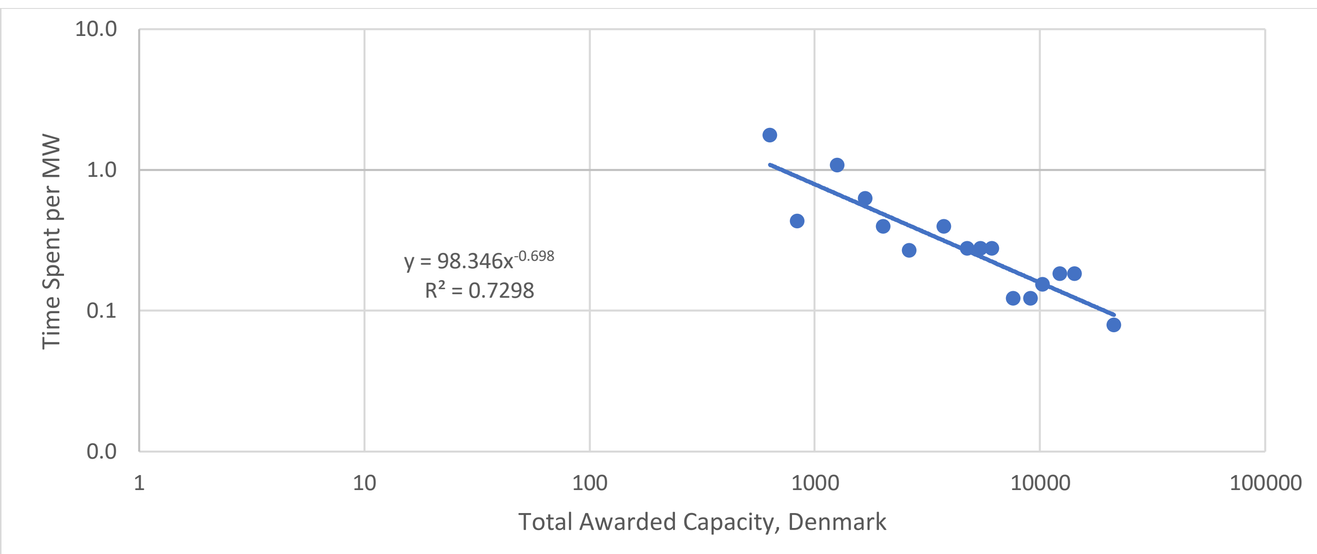


Figure 12 Learning curve for all leasing rounds, excluding open-door projects in Denmark.

From figure 12, it seems like the learning curve fits the data fairly well! The R^2 is now 0.7298 - meaning that it explains about 73% of the variation in the data. The LR is calculated to be about 38%, meaning that the time spent awarding a lease in Denmark is expected to decrease with about 38% every time the awarded capacity is doubled. This may be a lower percentage than calculated from Figure10, but it is likely more accurate as the learning curve accounts for more of the variation in the data than Figure 10 did. The decreased learning can also be explained by improvements in efficiency slowing down over time as processes stabilize (Kutner et al., 2005, p.533).

4.1.2. Development Timeline

Figure 13 shows the average time spent per MW on the different phases of all completed projects in Denmark, as well as the average time expected to be spent on the different phases for all projects that have been awarded leases. For the projects that were completed before January 2024, the average time spent was just under 40 days per MW of installed capacity. For projects that are currently underway, this is expected to be reduced to be about 25 days per MW.

Most notable about the time distribution is the time spent on leasing rounds. As mentioned in section 3.1.1., Denmark has had a slightly different approach to lease awarding than the other countries through the “open-door” policy. This has led the lease awarding process to be somewhat of a black box, where the lease awarding process is slower than that of a public auction – at least considering per MW awarded. As the “open-door” opportunity is being discontinued, it will be interesting to look at leasing round times, and what portion of the project timeline that makes up moving forward.

Two other portions that are expected to be significantly reduced, is the planning phase from when a lease is awarded until construction starts. As offshore wind becomes a bigger industry and companies learn different countries processes along with improving internal processes, this phase can reasonably be assumed to go swifter. The same goes for the process between when the first foundation is installed to when the first turbine is installed. Further, the fact that wind turbines and wind farms are both getting larger, combined with rapid development of system technologies, may also play a role in reducing the time -especially considering that the time is calculated per MW installed capacity and not per wind turbine or wind farm.

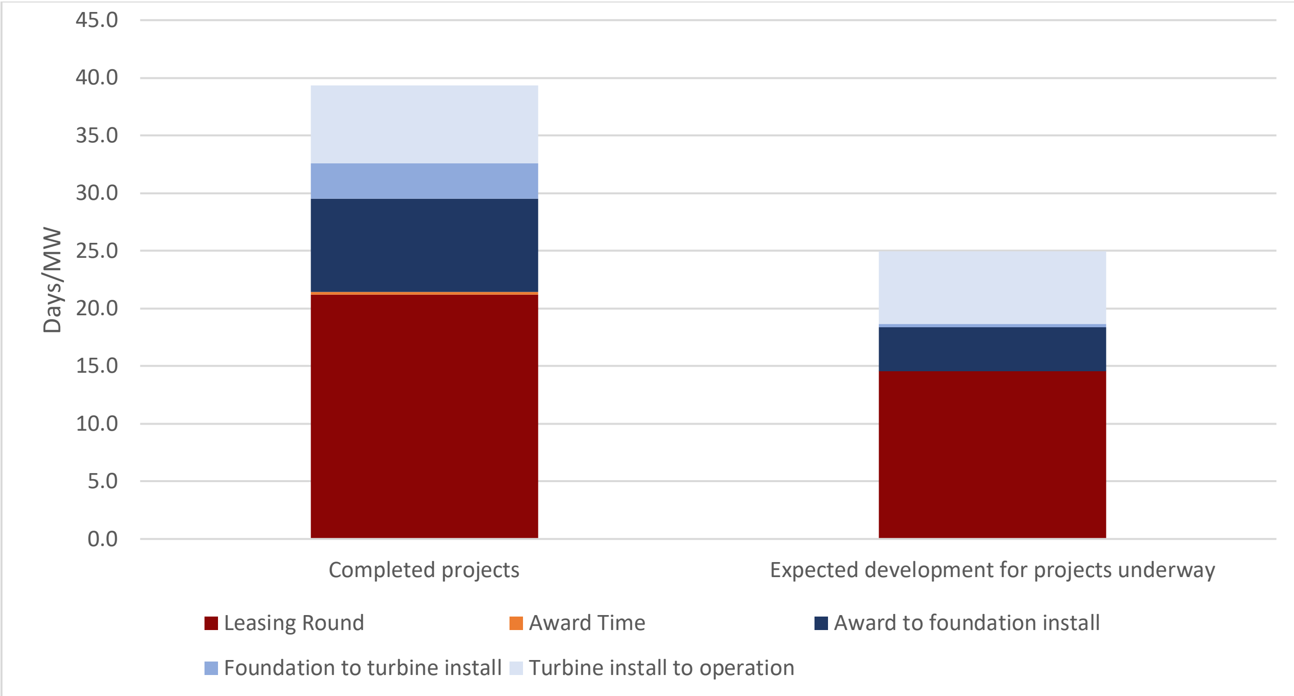


Figure 13 Historic and expected future time distribution for windfarm development in Denmark.

4.2. The UK

4.2.1. Policy Learning curve

In the UK, the tendering and leasing process is generally pretty standard. However, for most of the demo projects it has been very challenging to find the start date for the lease awarding processes. The demo projects missing a start date are marked in orange in Appendix 1. There can be many different reasons why the start dates have been hard to find, but to avoid big outliers and diluting the graphs, said demo projects will be excluded from all the analyses.

First, an analysis using all leasing rounds will be done. Next, an analysis will be done excluding all demo projects, as they are expected to be outliers and thereby somewhat diluting the data. Demo rounds in this thesis are defined as those rounds who have the word "demo" or "demonstration" in the name, or that are under 300 MW in installed capacity. As the UK only has one not-fully-completed leasing round (this leasing round started February 29th 2024, and will go through June 2025), all leasing rounds will be included in the analyses.

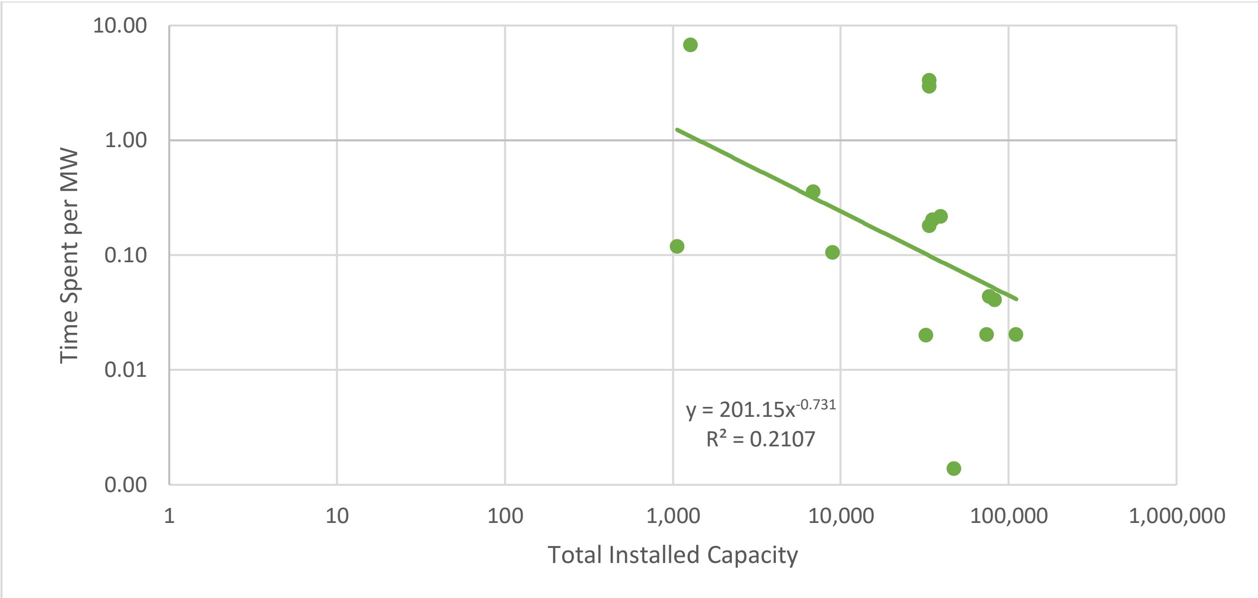


Figure 14 Learning curve for all awarded leases in the UK.

First out is the learning curve for all leasing rounds. Here, the R^2 is low, indicating that the learning curve only accounts for about 21% of the variation in the data. With the R^2 being that low, I will need to improve my data or look at the residuals to know if it is worth proceeding with any further analysis. The Demo projects in the UK are expected to be outliers, so let us see if our R^2 improves by removing these:

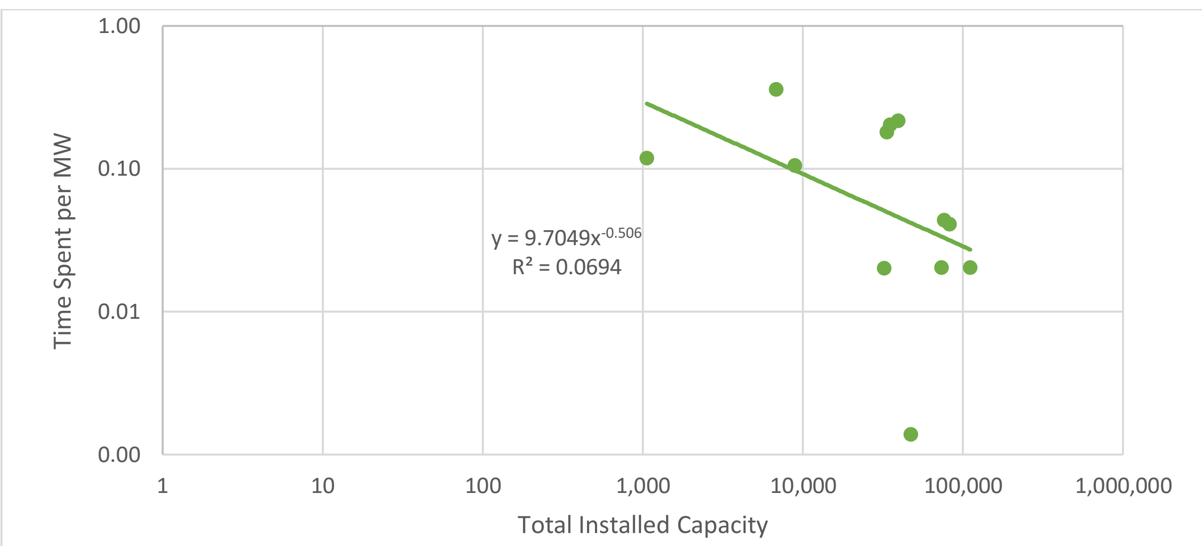


Figure 15 Learning curve for all awarded leases, excluding demo projects in the UK.

If the demo projects are excluded, as shown in figure 15, the R^2 surprisingly decreases quite a bit. To get a better indicator of whether the learning curve is representative or not, I will look at the residuals. As the R^2 is higher looking at all projects, I will be looking at those residuals first. The residuals can be seen in figure 16.

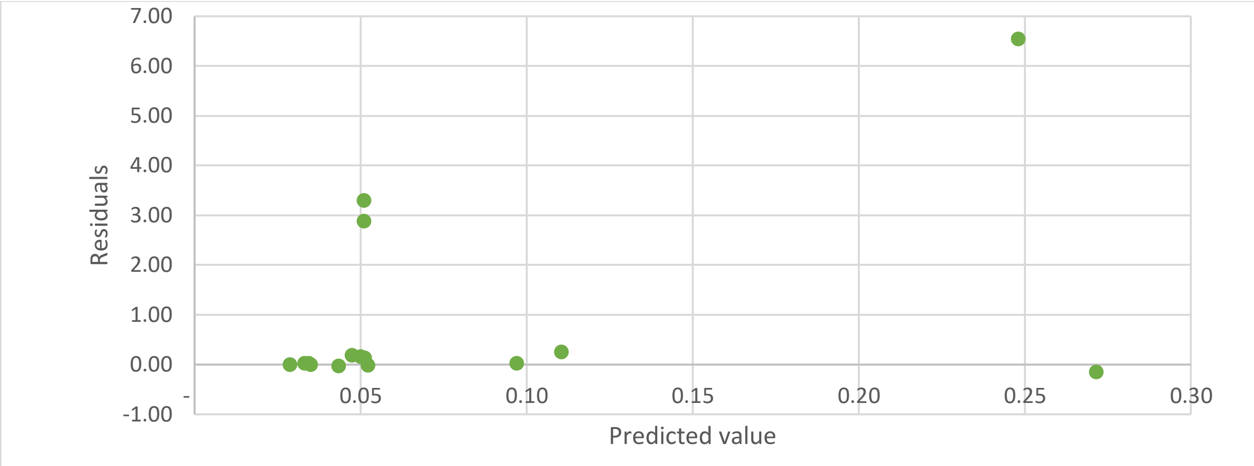
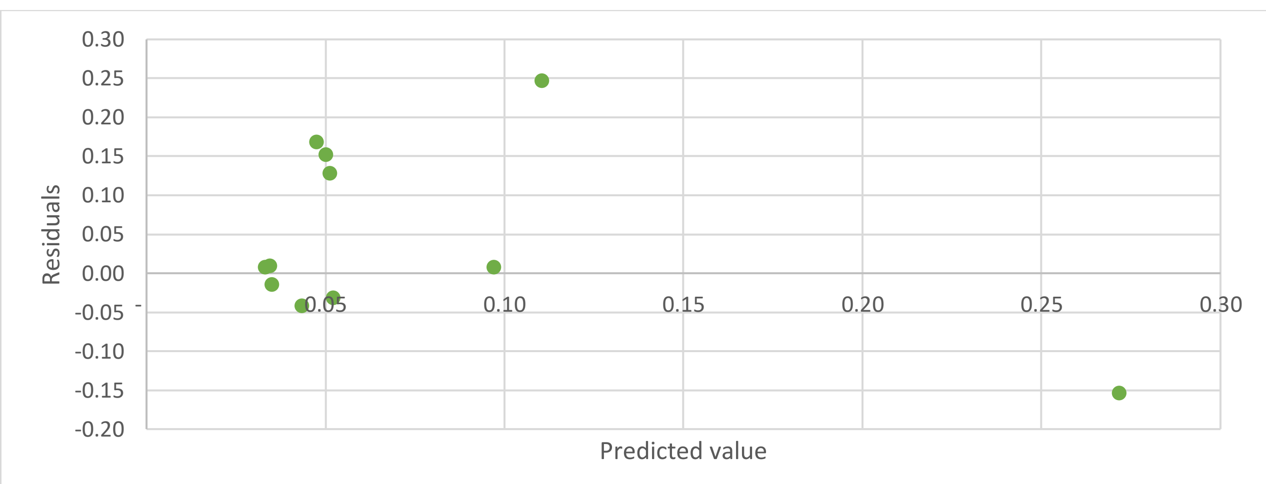


Figure 16 Residuals for the learning curve in figure 14, aka for all leasing rounds in the UK.

Immediately it becomes clear that 3 datapoints have residuals above 1 and are big outliers compared to the other datapoints. This also makes it seem like the residuals are not forming an evenly scattered horizontal band around the zero line, which indicates that the variances are not equal and that the relationship between the datapoints may not be linear.

When comparing the outlying datapoints to the raw data, it becomes clear that they are demo projects. Even if the R^2 was higher when including demo projects, that does not automatically mean that it is a better or more accurate model. As the demo projects are big outliers, I will remove them and make the residuals using the same datapoints as used in figure 15. The new residuals can be seen in figure 17.



.Figure 17 Residuals for the learning curve in figure 15, aka for all leasing rounds in the UK excluding demo projects.

As there only are a few datapoints to look at, the spread can be a little challenging to interpret. The datapoints do not form a clear pattern, and do to a much greater extent stay close to the zero line now. This indicates that linearity is a reasonable assumption. Some of the dots in figure 17 go higher to the positive side than to the negative side, which indicates that the variance in errors may not be fully equal on both sides -however, there might be too few datapoints to fully conclude on this. Further, there are a few outliers, but a lot fewer and smaller than in figure 16. These could be due to few datapoints and not due to being big outliers -again, there are too few datapoints to make a solid conclusion. When looking at the placement of these smaller outliers, the two biggest ones both have a high predicted value, meaning that they would be among the very first leasing rounds conducted in the UK. Comparing that to the leasing rounds in Appendix 1, the cumulative capacity increases from about 1000 MW to almost 7000 MW awarded capacity. An almost 7-doubling in awarded capacity does not happen regularly and it therefore makes sense that this would not follow the trend, or predicted value, as closely as the rest.

As mentioned, there might be too few datapoints to make a definite conclusion, but based off of the residuals in figure 17, I will proceed with the analysis of the learning curve in figure 15, as this seems to be the most reliable learning curve of the two.

The LR for UK leasing rounds can be calculated to be about 30%, meaning that the time spent awarding leases in the UK is expected to decrease with about 30% per MW every time the awarded capacity doubles. This is lower than in Denmark, but as Kutner et al. (2005) explains, this makes sense as improvements in efficiency slows down over time as processes stabilize (p.533) and the UK has a much higher awarded capacity than Denmark does.

4.2.2. Development Timeline

Figure 18 shows the average time spent per MW on the different phases of all completed projects in the UK, as well as the average time expected to be spent on the different phases for all projects that have been awarded a lease or are further into the process. For the projects that were completed before January 2024, the average time spent was roughly 28 days per MW of installed capacity. For projects that are currently underway, this is expected to be reduced to be just under 15 days per MW.

Most notable about the UK graph is that the time from when a lease is awarded until construction starts by installing foundations, makes up such a big part -in fact, it almost accounts for half the time with 13.5 days/MW. This is a surprisingly large portion! A possible explanation for this, according to Mr. Oliver Stephenson and Mr. Kasper Grytnes (personal communication, January 2024), is that in the UK companies apply for financial governmental support, such as CfDs, after they have been awarded the seabed lease to construct a windfarm. Most companies will not start construction until they are sure to have a financially viable business case, and therefore do not start construction until the CfD contract with the government is signed. This often takes some extra time to get in place and may therefore add extra time to this particular phase.
In the expected development it seems like this is not reduced much. This could partially be due to the reason listed above. However, in the data, most windfarms under development do not have as detailed information for the process as the completed windfarms have. They also have significantly less datapoints for the construction process than the projects under development in Denmark and Taiwan have. Many windfarms under development in the UK therefore have the entire construction phase included in the "Award to foundation install" phase instead of spread out between the different construction phases. It should therefore be read as the entire construction process for that particular pillar rather than reading too much into it as a phase of construction. More on this in section 6.1.

Another notably big chunk of time for the completed projects, is the time it takes from the turbine installation starts until the windfarm is operational. Historically, this phase has taken 7.6 days/MW. One possible reason for this could be the scope of the projects. Sometimes the developer has to connect the windfarm to the grid themselves as part of the development. Other times, this is something the governments or their utility company does. Sometimes it may even be a split effort. What is included in the scope could affect the projects timeline quite a bit, as internal communication and familiar processes often are more efficient than external communication and (at least somewhat) unfamiliar processes.

Another explanation could be that turbines are getting increasingly bigger and more technologically advanced. This could potentially lead to longer and more complicated installation processes. However, the wind turbines are also increasing in capacity, so this is not expected to make a huge difference, as we are looking at time per MW installed capacity.

Lastly, it is interesting to note how the award time is reduced from 3.5 days/MW for completed projects, to 1.4 days/MW for those under development. This could be due to the fact that the UK has very few demo projects that are currently under construction, while they do have quite a few historically. Demo projects have a low installed capacity along with often being related to exploring a new territory of some sort. This means that both the MW is lower than that of a full windfarm, as well as the processing time assumably taking longer due to new factors or territories needing to be considered by the TCE. Another explanation could be that the windfarms are getting bigger, so even if the processing times are the same, they would appear shorter as the installed capacity increases.

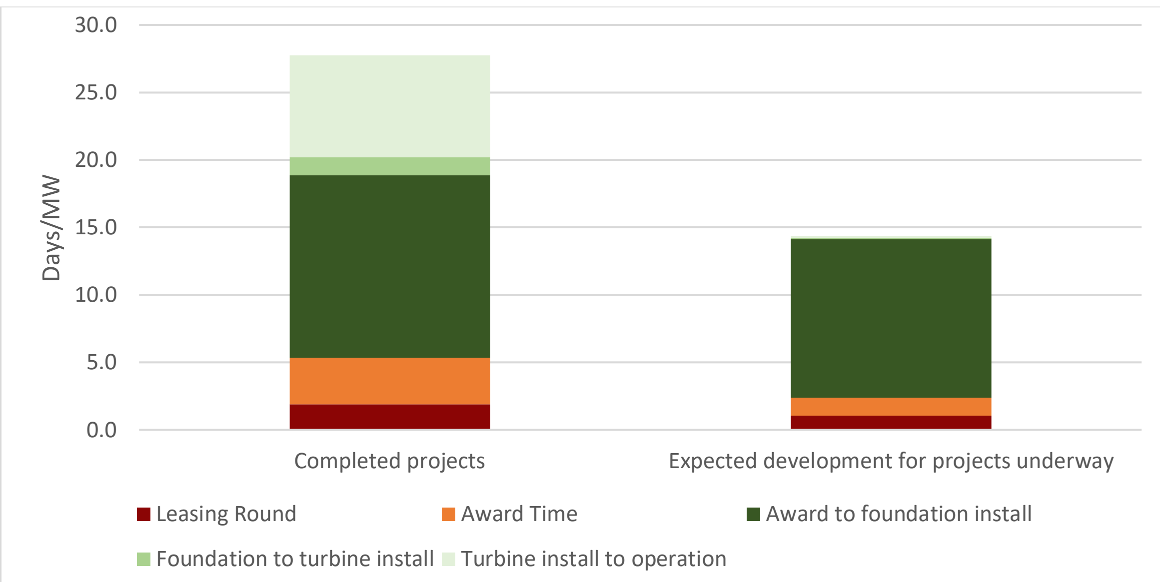


Figure 18 Historic and expected future time distribution for windfarm development in the UK.

4.3. Taiwan

4.3.1. Policy Learning curve

The leasing rounds used to generate the learning curves for the leasing rounds in Taiwan, with its accompanying data can also be found in Appendix 1.

Taiwan has had significantly fewer leasing rounds than Denmark and the UK, and therefore there are also less datapoints to use when generating the learning curve. Taiwan Phase 3.3 is excluded from the learning curve, as it does not yet have complete data. Taiwan Phase 3.2 is ongoing while this thesis is written, and there are several windfarms that still could be cleared to participate in this round instead of Taiwan Phase 3.3. There are also some windfarms that are working hard to be cleared in time, and if they do not reach the deadlines, will be participating in Taiwan Phase 3.3 instead of Taiwan Phase 3.2. The awarded capacity for Taiwan round 3.2 is a government estimate, but there is, as explained, some uncertainty surrounding the exact number of MWs awarded in this round.

As there is so little data, I have chosen to only make one learning curve including all the leasing rounds. This is because I do not believe that excluding their one demo project, or looking at historical data vs looking at the expectant development would make a huge difference. The learning curve for leasing rounds in Taiwan can be seen in figure 19.

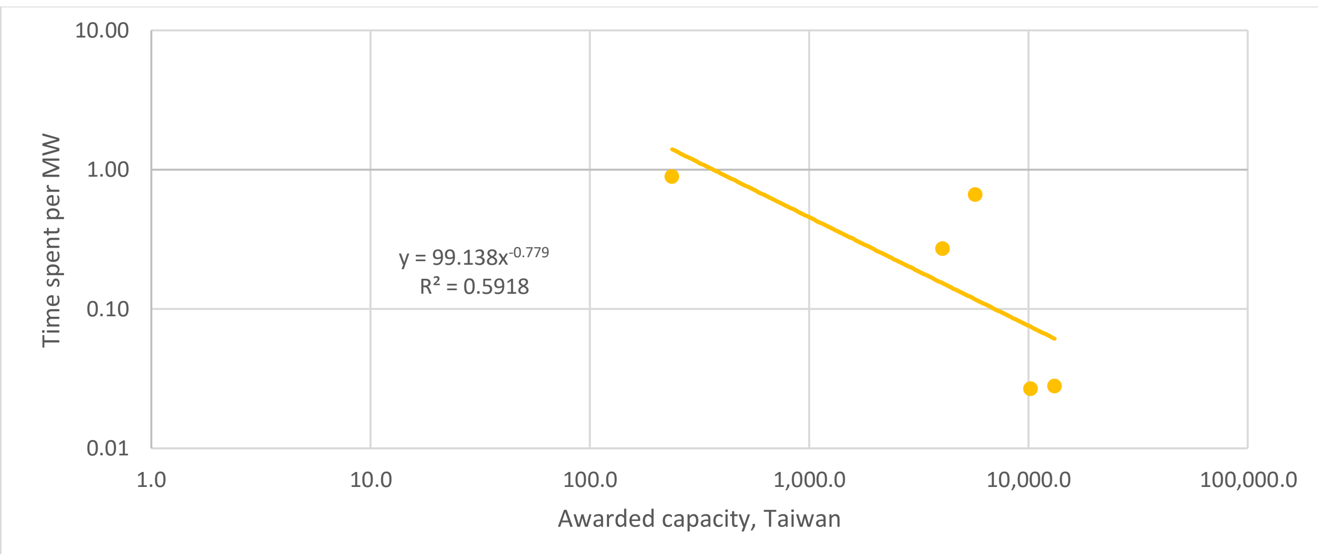


Figure 19 Policy learning curve including all leasing rounds in Taiwan.

From the learning curve in figure 19, we can calculate the LR to be about 42%. This means that the Taiwanese government can expect that their time spent awarding each MW will decrease with 42% every time the offshore wind awarded capacity doubles. The R^2 is calculated to be about 59%, meaning that the learning curve accounts for 59% of the variation in the data.

4.3.2. Development Timeline

Figure 20 shows the average time spent per MW on the different phases of all completed projects in Taiwan, as well as the average time expected to be spent on the different phases for all projects that have been awarded a lease or are further into the process. For the projects that were completed before January 2024, the average time spent was about 70 days per MW of installed capacity. This is extremely high compared to Denmark and the UK. Part of this is likely due to some of the startup challenges Taiwan has had as mentioned in section 3.2.1.. The fact that not very many additional projects have been completed yet, to provide a more balanced view, is also likely contributing to the high day/MW ratio. On the other hand, this huge difference in the time/MW ratio between the different countries just highlights the need for emerging markets to do thorough research on and be intentional about their policy choices – given that they intend to implement and build an offshore wind industry quickly, or at least at the same pace as the established industry.

For projects that are currently underway, the time spent per MW is expected to be reduced to only about 8 days per MW. Although it is realistic for projects in Taiwan to go much faster than what they have in the past, it may not be realistic to be that much faster than both Denmark and the UK –whom both have more experience, predictability, and trust from the industry. However, as most challenges mentioned in section 3.2.1. are being resolved, and the political processes is gaining both trust, stability, and predictability, it is, as mentioned, very likely that the time spent on developing windfarms in Taiwan will be reduced substantially.

As seen from figure 20, the by far biggest chunk of time in Taiwan has been spent on the phase between when a lease is awarded until construction has started. The lack of predictability and trust as mentioned above and explained in section 3.2.1. has likely played a big role in this. Uncertainty around subsidies and unclarity around local policies, such as the LCR, have likely been big hurdles and prevented businesses from knowing if they have a viable business case and thereby prevented them from making the final investment decision. The fact that the LCR has been put in place without an established industry in the country to support the requirement has likely contributed to the delay in construction start.

From the completed projects, the only other phase that I would consider long is the phase from when turbine installation starts until the windfarm is in operation. This one is about as long as in the UK, with 7.7 days/MW in Taiwan. However, as most projects in Taiwan are connected to the grid by the national utility company Taipower (Gao et al., 2021), the scope can be assumed to be slightly narrower, and the longer time may be correlated to the commercial companies needing to collaborate with the public company to connect the windfarms to the grid. Gao et al. (2021) also mentions how Taipower has struggled to connect the grid to offshore wind farms and to have enough grid capacity to connect the windfarms in a favorable way. This is a process that likely will be going faster as the grid in general is expanded as well as Taipower gains experience working with offshore wind in contrast to onshore power plants.

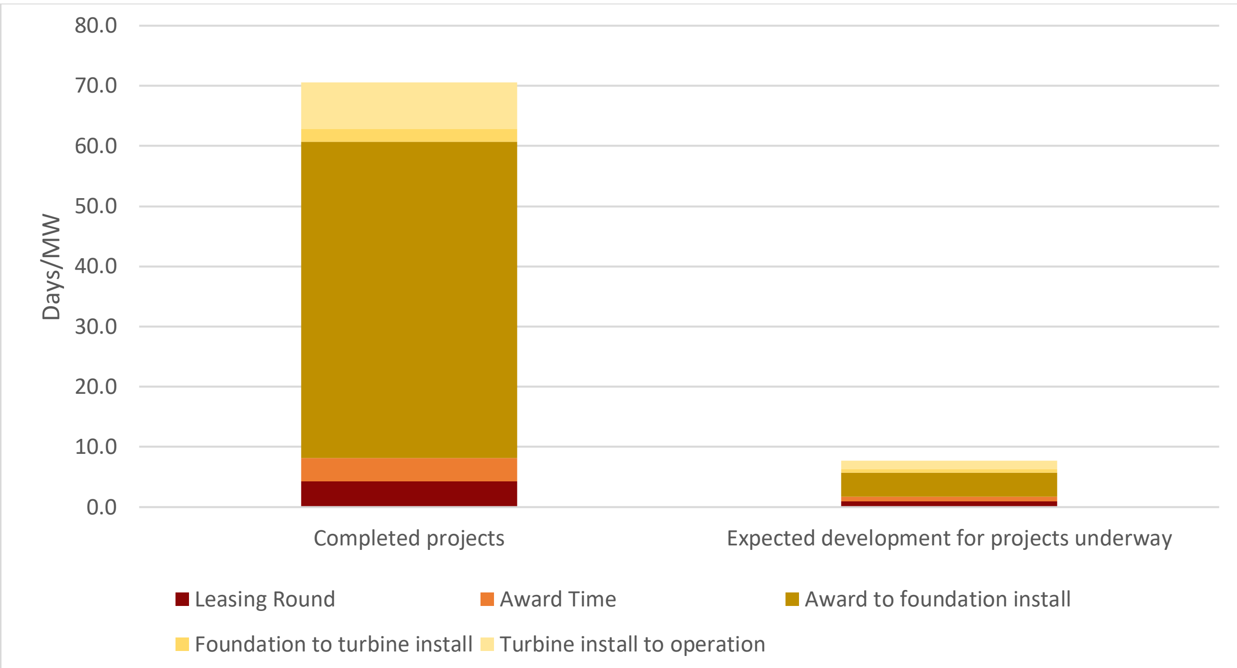


Figure 20 Historic and expected future time distribution for windfarm development in Taiwan.

4.4. Time distribution summary

The average time distribution for the development of a windfarm across Denmark, the UK and Taiwan can be found in figure 21. As the UK has the biggest portfolio of offshore wind, the figure is naturally resembling their time distribution the most. The expected development for projects underway is especially similar to the UK. This could both be because they are developing the most installed capacity, or it could be because their estimate is in between Denmark's and Taiwan's estimates -or it could be a mix of the two.

For the time distribution of completed projects, it is interesting to see how close the overall average distribution across the three countries is to the UKs historical average -which was the lowest of all the three. Figures 22 and 23 display the individual country data side-by-side for easy comparison. The overall distribution being so close to the UK is likely due to the UK having the biggest portfolio of completed projects. Further, it is interesting to see how the leasing round plays a relatively big part compared to that of the UK and Taiwan. This is likely due to Denmark having historically long leasing rounds due to the "open-door" procedure. Further, it is interesting to see how the award to foundation install time period accounts for less than half the time (14.7 days / 33.7 days) spent developing a windfarm. -especially considering how this was the by far largest time period in both the UK and Taiwan.

As in every country, the time from the turbine install starts until the operation starts also accounts for a fair amount of time when looking at the total. This time chunk accounts for 7.4 days, which is very similar to that found in every country individually (6.8 days in Denmark, 7.6 days in the UK and 7.7 days in Taiwan), but looks disproportionally big as the total time varies greatly between the countries. The fact that this is so similar across all countries despite big variations in almost every other aspect indicates that this process might be optimized -or that none of these three countries have found a more efficient way of making the process happen.

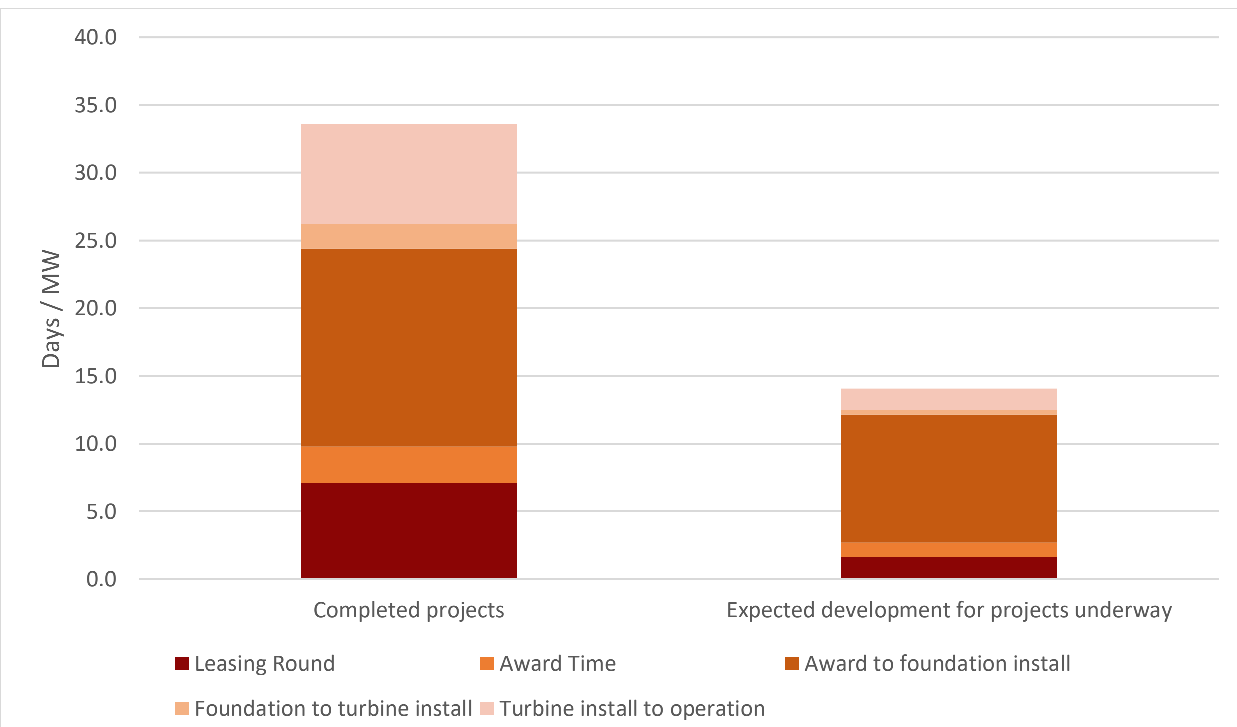


Figure 21 Average time distribution per MW for all windfarms constructed in Denmark, the UK and Taiwan.

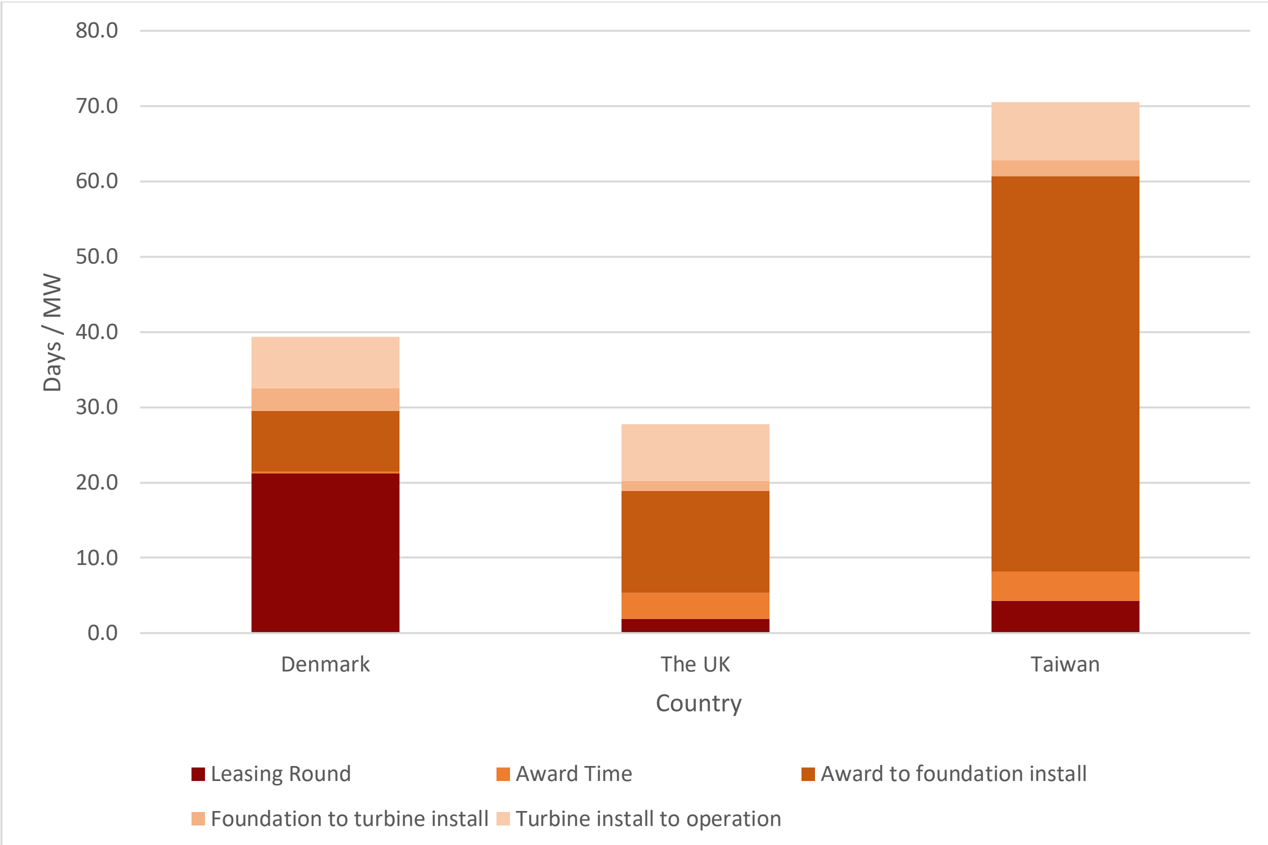


Figure 22 Historical average time distributions across the three countries.

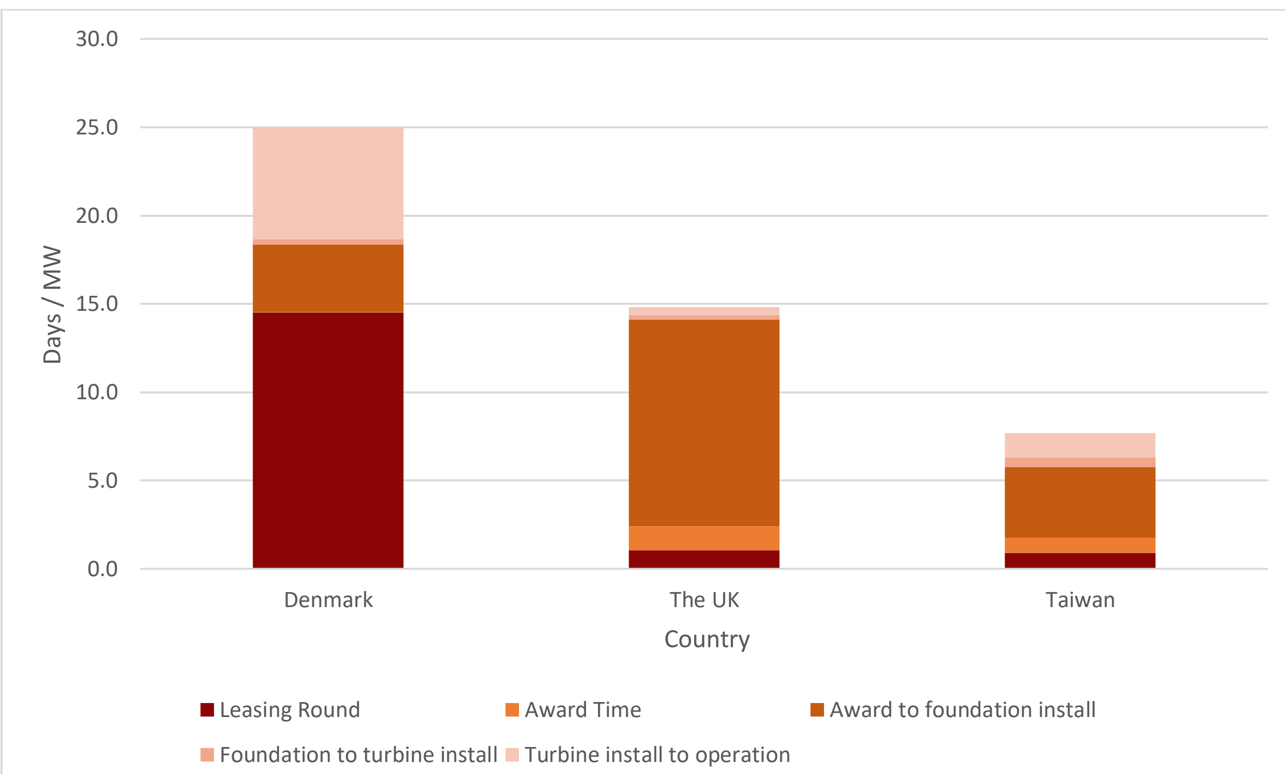


Figure 23 Expected average time distribution for projects underway across the three countries.

5. Discussion

5.1. Comparison of policies

5.1.1. Establishing an offshore wind industry

Denmark has historically combined government-led initiatives with competitive auctions to stimulate its offshore wind sector. Initially, through agreements such as the "100 MW Agreement," Denmark mandated utility companies to develop wind power without subsidies, which has evolved into a competitive auction system allowing international bidding. If companies were to attempt a similar agreement today, it would likely have to be of a larger nature than 100 MW due to technical advancement. Nonetheless, it is an interesting approach and incentive that was launched by the Danish government. Danish policies have evolved to aim for long-term stability and ambitious renewable targets, like achieving 50% of electricity from wind power and covering all electricity consumption with renewable energy by 2030. Their strategy included an "open-door" policy, allowing developers to propose projects in areas of their choosing. This has likely attributed greatly to their development, and likely allowed them to develop the industry using less government resources than the UK and Taiwan. In recent research, industry representatives have actually indicated a preference to locating and finding suitable offshore wind sites themselves (Do et al., 2022), indicating that the “open-door” policy might have been a smart move from the Danes. Regardless of the approach, the leasing process in Denmark has been well-coordinated in recent years, involving multiple key permits and a comprehensive environmental impact assessment before any lease is given.

The UK's approach has focused more on growth, targeting 40 GW of offshore wind capacity by 2030. Their history shows a strategic policy development, starting with the Electricity Act of 1989 and evolving through various instruments like the ROC and CfDs to support renewable energy. The stability and predictability along with good financial incentives has led the UK to become one of the main players with the second largest offshore wind portfolio globally. The UK's leasing process is known for its structure and inclusivity, ensuring sustainable and responsible development. It emphasizes competitive auctions to award leases, with a comprehensive financial framework to support project development.

Taiwan's offshore wind policy reflects that it is a rapidly growing sector. With a strategic framework set out by the MOEA, Taiwan has used demonstration projects and competitive price-based auctions with mandatory LCRs to kickstart its offshore wind industry. They have faced some challenges, including the challenge to fulfill LCRs, but seem to still be on track to achieve 3 GW of installed capacity by 2025. Taiwanese policies have mostly been centered around stimulating economic growth and developing new industry sectors around offshore wind. Even if it takes a little longer to get the offshore wind industry established, Taiwans approach will likely lead them to have great knowledge and competence in the field that it later can export and use to grow their economy.

5.1.2. Tendering and lease awarding systems

The current tendering processes in Denmark, the UK, and Taiwan carry several similarities, but also a few key differences in approach. These are further shaped by their individual policy environments and strategic objectives.

Denmark has evolved its lease award system from predominantly awarding leases through the "open-door" policy to now implementing a competitive auction-based system. As mandated by the EU, the transition aimes to increase competitiveness. This is expected to drive down the cost of offshore wind. Future projects, previously approved under the "open-door" policy, are expected (but not yet announced) to be auctioned publicly. The leasing process involves several key permits, including licenses for preliminary investigation, construction, and energy production, all coordinated by the DEA, with extensive environmental assessments and public consultation before the tendering process starts. That way, developers can be confident in a problem-free (at least from the public perspective) lease agreement once the lease is won.

The UK uses a well-developed and structured lease award system administered by TCE in England, Wales, and Northern Ireland, and The Crown Estate Scotland for projects on the Scottish seabed. This system is also characterized by public auctions, where leases are awarded through competitive bidding. The process is transparent and involves multiple stages, including PQQs and ITT stages that assess bidders' technical and financial capabilities. The UK's large and efficient leasing rounds have been instrumental in helping the country stay on track to reach 40

GW installed offshore wind capacity by 2030. The process also includes EIAs to ensure sustainable development. TCE's role in managing the seabed and licensing ensures a consistent approach across the UK –even with slightly different processes in Scotland.

Taiwan's lease award system has been developing rapidly, with a focus on zoning regulations and strategic environmental assessments to facilitate offshore wind development. The system is managed by the MOEAEA, who have emphasized demonstration projects and zonal development. Taiwan combines qualification reviews with price auctions. This approach allows the government to select developers based on technical and financial evaluations before proceeding to a price-based auction for grid allocation afterwards. Taiwan's policies, particularly the LCR and its FiTs, aim to attract developers while fostering a local supply chain for the offshore wind industry. The government has had a certain degree of success in auction design and awards, but so far it has had no success in making sure that projects will be delivered on time (Kubitschek et al., 2023).

Denmark, the UK, and Taiwan have all developed lease award systems that reflect their policy priorities and market conditions. All countries now have a focus on competitive auctions. In the UK and Denmark, these are now all price-based, on the condition that the developer can be trusted to deliver on their bids. This is checked for in advance through e.g. PQQs. In Taiwan they are operating with a very similar system, but with a greater emphasis on developing local industry through the LCR. The fact that all three countries come from very different approaches but now all operate with the same price-based auctions give reason to assume that this is the best tendering system.

5.1.3. Incentive mechanisms and their effects

Incentives such as CfDs, LCRs, FiTs, ROCs, as well as policies creating stability and predictability play significant roles in influencing the development, construction, and implementation speed of offshore wind projects.

CfDs provide long-term price stability and revenue certainty for developers by guaranteeing a fixed price for the electricity generated over a specified period. This reduces investment risks associated with fluctuating market prices, and thereby makes investing in the given market/country more attractive to investors. The UK government uses CfDs as their flagship scheme for procuring high volumes of clean energy at the lowest possible cost for consumers (Great Britain Department for Business and Trade, n.d.). CfDs attract investors and developers by offering a predictable revenue stream, which, in the case of the UK, has laid ground for a speedy and substantial development of offshore wind projects, which can be seen by the size of their portfolio.

LCRs mandate that a certain portion of the project's components, such as turbines or other equipment or subcontractors used to work on the windfarms, must be sourced locally. The goal of LCRs is to promote domestic industry growth, create jobs, and retaining economic benefits within the country. While LCRs can potentially increase costs and introduce logistical challenges, the latter one being the cause of some projects in Taiwan being slowed down, they can also stimulate the growth of a domestic offshore wind industry. By incentivizing local manufacturing and supply chain development, LCRs can contribute to the overall expansion and competitiveness of the downstream offshore wind industry in a country. In the case of Taiwan, it seems to have led to the establishment of an offshore wind industry taking longer than it otherwise could have -at least in the short term. But, as the industry is becoming increasingly established and domestic companies gain the needed expertise, one may assume that the LCR will help stimulate domestic economy. However, according to Hogan (2021), this does not necessarily have to be the case, as LCRs often give local producers incentives to specialize in simple and unsophisticated components, as well as creating products that are either more expensive or inferior (or both) to that which could have been obtained through international trade. Time will tell which effect the LCR in Taiwan has on both its offshore wind industry and domestic economy.

FiTs offer guaranteed payments for electricity generated from renewable sources, often set at a premium above market rate. They are often used to incentivize renewable energy production. FiTs can facilitate rapid development of offshore wind projects by providing attractive financial incentives for developers. However, they may also lead to higher costs for electricity consumers if not carefully managed (Do et al., 2022), as seen in Taiwan where a high FiT both attracted a large number of offshore wind projects in 2016 and 2017, but also created problems as awarding said FiT to all projects. This was because the FiT would cause a huge burden on Taiwanese consumers, which resulted in the MOEA being sued for misconduct (Gao et al., 2021). From this experience it seems like starting with a FiT to initially attract investors may be a good idea, but over time, as the offshore wind industry matures and costs decrease, it may be wise to transition from FiTs to other mechanisms like CfDs.

ROCs are tradable certificates awarded to energy producers for each unit (usually MWh) of energy produced from renewables. The requirement is for transmission or grid companies to have a certain percentage of their power sold be documented renewable energy. This way, the ROC serves as a subsidy mechanism, as the grid companies make sure to adopt and utilize renewable energy -even if it is slightly more expensive. There is less political risk to this incentive, as it generally is less politically sensitive than FiTs (Do et al., 2022). Still, developers receive additional revenue, which accelerates both project development and construction.

Regardless of which policies are implemented, a survey done by Do et al. (2022) found that the most important barrier when establishing an offshore wind industry is unforeseeable policy and incomplete administrative procedures. This was listed as a key barrier by 100% of their survey respondents. Policies that create stability and predictability in regulatory frameworks, permitting processes, and market conditions are crucial for fostering investor confidence and reducing project development risks. Stable and predictable policies provide a conducive environment for long-term planning and investment in offshore wind projects. By looking at the recent development in Taiwan, it becomes clear that having a predictable and reliable political process is a crucial part of establishing a foundation that the offshore wind industry in a country can be built upon. Further, both from Do et al. (2022)'s research and Taiwan's experience, it becomes clear that this predictability includes having sufficient infrastructure, such as supply chains and sufficient grid connection and capacity in place before tendering starts. By having this, developers can make informed decisions, secure financing easier, and execute projects more efficiently.

Overall, which policies should be implemented depends on what stage of life the offshore wind industry in each country is in. The policies all have the potential to accelerate the development and construction speed of offshore wind projects by providing financial incentives, reducing investment risks, stimulating domestic industry growth, and creating a stable regulatory environment. However, the efficacy of these policies depends on their design, implementation, and adaptation to the specific context and challenges of each country's offshore wind sector.

5.2. Comparison of learning curves

When it comes to the learning curves, it seems like the learning curve that best fit the data is the one representing Denmark's public leasing rounds as this one has the highest R^2, but all countries have produced a seemingly reliable learning curve. Out of these, Taiwan has the highest Learning Rate, meaning that they seem to be learning the fastest. This also makes sense given that the offshore wind industry is the youngest there. However, due to somewhat lower-than-hoped R^2 values, there is a chance that the data may not fit the curve as well as one would like, making the learning curve equation have less of a "goodness-of-fit" as well. If the equation for the learning curve does not fit the data that well, there is a chance that the LR calculated from the equation may not be as reliable as one would hope either.

It is important to keep in mind that the unit for the y-axis is time/MW allocated. This could indicate that the processes are improving and going faster -which is what one would hope for. However, as the windfarms are getting bigger this number is likely to be reduced, simply because the MW allocated is increasing. One could argue that the processes are swifter if the time spent awarding a 100 MW windfarm and a 1000 MW windfarm is the same -as there are more considerations the regulatory bodies must consider before allocating leases to such large windfarms. However, even if there is more work and the processes would be taking longer, the increase in time is likely not proportionate to the increase in size, and bigger windfarms would assumably lead to shorter leasing rounds when looked at in time/MW allocated. In fact, Mayor (2020) has found that with different desalination technologies, learning seems to decrease with between 3 and 13% once economies of scale is taken into account. By looking at the raw data (can be seen in Appendix 1), it does seem like the windfarms consistently are getting bigger, meaning that this could be a contributing explanation for the LR. Mayor (2020) did however find that learning (and not economies of scale) is the main driver for improvements in the desalination process. Assuming that the finds transfer to offshore wind, one may assume that learning is slightly lower than calculated, yet learning, and not economies of scale is the main reason for technology improvement.

It becomes more interesting that the UKs leasing rounds resulted in a learning curve with low R^2 values. Out of the three countries, they are the ones with the highest installed capacity, the most projects built as well as the most projects underway -and naturally also the most leasing rounds. The UKs windfarms tend to be getting increasingly bigger in size -even if the leasing rounds do not necessarily follow a consistent pattern on this, as can be seen in Appendix 2. However, when that is said, the leasing rounds in Taiwan do not follow a clear and steady increase in awarded capacity during leasing rounds either. The ones in Denmark seem to have somewhat more of a trend, although not a perfect increase here either. Following Mayors (2020) findings, economies of scale is likely not the explanation for why UKs leasing rounds struggle to produce a learning curve with a high R^2, nor why they have the lowest LR of the three countries.

One hypothesis for the UKs lack of learning curve could be that their leasing rounds are fully optimized and therefore there is less learning occurring. This argument is supported by Kutner et al. (2005). This hypothesis is further strengthened by the fact that the UK has the largest offshore wind portfolio of the 3 countries and are among the global leaders on offshore wind. It is also strengthened by the development timelines, where the UK has the shortest timeline per MW installed, and by the fact that it seems like Denmark and Taiwan slowly might be moving towards adapting a more UK-like policy. However, not having any learning still sounds unlikely. Another explanation might be found when looking at how big the total awarded leases are in each leasing round. As seen in Appendix 2, the UK seems to have a wave-like pattern. As the data is excluding demo projects (and all projects under 300 MW), this cannot be an explanation for why there suddenly are several smaller leasing rounds. When looking at the raw data, or the leasing round themself, many of these seem to be extension rounds or single-project leasing rounds -which naturally are smaller than multi-project leasing rounds. Therefore, these rounds may pollute the data and cause the learning curves to not be representative -even if they are not demo rounds.

5.3. Sources of error and other factors to consider.

The biggest source of error found in the time distribution is likely in the accuracy of the data used to compare historic and expectant development. Comparing an expectant development, where events are anticipated but have not yet occurred, with historic development, which is based on accurate data, can introduce significant sources of error due to the lack of data points, or lack of accuracy of data points for future events. In the historical analyses, data points are reliable and accurate as the dates used have already occurred. However, when analyzing expectant developments, such as future offshore wind leasing rounds or policy implementations, the absence of empirical data makes it challenging to predict outcomes with certainty. Factors like market dynamics, technological advancements, and regulatory changes can influence future developments in unpredictable ways. Further, a governments desire to get a windfarm up and running as fast as possible may give companies incentives to give their quickest, best-case-scenario time estimate instead of a realistic one. As a result, relying solemnly on either just historical data or just the expectant development to inform projections or expectations for future developments may overlook unique circumstances, emerging trends, and unforeseen variables that could impact outcomes differently. Therefore, it's essential to approach expectant developments with caution, and acknowledge the inherent uncertainties and limitations associated with forecasting future events based on historical data alone.

Another reason for discrepancies in the time distribution data may be the size of the windfarms in the different countries. The analyses have been done with time in days/MW to try to correct for the fact that windfarm sizes can be vastly different, but having projects that average 100MW versus having projects that average 1000MW will likely make the 100MW projects appear to take extremely long as there will be efficiency and thereby advantages in larger projects. For reference, the average size of windfarms are shown in figure 22.

Country:	**Current average size windfarm:**	**Average size of windfarm under development:**
Denmark	144.5 MW	342.3 MW
The UK	358.4 MW	1000.0 MW
Taiwan	153.3 MW	513.2 MW

Figure 24 Average size of windfarms.

For the learning curves, there might be a slight systematic error due to narrow scope. Usually when generating learning curves one looks at a global scale, as learning happens globally. However, one country's policy does not directly affect another, and it would not make sense to look at learning curves for leasing rounds on a global scale. Countries could still learn from another by noticing how one policy might either be very efficient or cause huge delays. So even if looking at a global policy learning curve does not make sense, there is likely some spillover in learning between countries that is not accounted for in the learning curve analyses or in this thesis.

Geopolitical factors play a significant role in influencing the timelines for constructing wind farms. Events such as the war in Ukraine has, as an example, caused a fluctuation in steel prices. These price increases severely impact the cost of wind turbine components and infrastructure, which mostly consists of steel (D, Franco, personal communication, July 2023). This may lead to delays as developers may need to reassess budgets and sourcing strategies. Geopolitical tensions or challenges, such as those created by COVID-19, can disrupt supply chains and delay project timelines due to material shortages or logistical challenges. However, it is also important to mention that the geopolitical situation can swing the pendant in the other direction as well. With gas prices increasing dramatically as a result of the sanctions on Russia, power prices in Europe skyrocketed. This increase in sales prices gives power producers an incentive to expand their production to get as good prices as possible on the power they produce.

Recently, several companies have faulted on and withdrawn from their contracts -stating challenges related to inflation in steel prices and supply chain issues as the reason why (Reuters, 2024). This, or any other reason why a developer withdraws from their lease contract, usually causes the leasing process for the given area to start over again, which again leads to a longer timeline from when the lease was first opened to when the windfarm is in full operation. This seems to be more of a recent development due to geopolitical challenges, and have therefore likely not affected the data much, but it is something to be aware of as a deviation from standard procedure moving forward.

Given the challenges recently experienced by countries like the US, the UK and Norway in attracting bidders for offshore wind leasing rounds (Rustad, 2024), there is reason to question the realistic expectations for forthcoming leasing rounds, especially in the current market context and geopolitical climate. The challenge to attract bidders could become increasingly difficult as more and more countries develop an offshore industry, and developers can get increasingly selective in which countries they choose to invest in (O, Stephenson, personal communication, October 2023). The challenge to gain interest from developers may highlight broader industry challenges, such as uncertainty surrounding regulatory frameworks, financial incentives, and market conditions. In a market grappling with issues such as fluctuating steel prices, geopolitical tensions, and constantly evolving energy policies, the prospect of successful leasing rounds may become more complicated than before. Developers may adopt a cautious approach, reassessing investment strategies and prioritizing projects in regions with more stable conditions or higher potential returns. Therefore, while leasing rounds are planned with the intention of fostering industry growth, attracting investment to increase R&D and drive down the cost of producing power from offshore wind, the current market dynamics and geopolitical uncertainties suggest that achieving desired outcomes may become challenging moving forward.

Lastly, there is always a risk relating to weather. If winds or waves are too high, the vessels constructing, and later doing maintenance on the wind turbines will not be able to operate in planned ways. Unforeseen weather challenges may therefore cause delays in construction, and even shorten the life expectancy of a wind turbine or a wind farm. Per now, this is likely not something that would cause great delays or prevent investors from investing or making the final investment decision, but as global warming and extreme weather increases, this is something for policy makers and regulators to keep in mind and be aware of.

5.4. Implications for the industry

There are a few takeaway messages and findings both for existing markets and for emerging markets. To me, the main findings and maybe even surprise is the vastly different time distributions within the different markets. Since the time distribution bar charts are done per MW to be easily comparable, these differences become huge once scaled to fit existing projects. It is important to note that the time spent per MW likely will decrease as projects become bigger.

This can e.g. be seen as the average size of Denmark's expected developments is about the same size as the UKs historical development. By comparing these two time distributions, the difference is reduced to be about 3 days instead of about 11 days, which seems a lot more reasonable. However, when scaled, 3 days is still a significant amount of time -both for the countries trying to benefit from clean energy production and for investors and developers. If the 3 days difference is multiplied with the 350 MW windfarms that is the average size of the historical development in the UK and the expectant development in Denmark, this comes out to 1050 days, or just under 3 years difference from when the leasing process starts until the windfarm starts operating. This could end up being 3 years of lost revenue for the companies, which makes investing less appealing. For the countries awarding leases, this time period needs to have the electricity needs met by other technologies -which, based off of Hossein et al. (2019), often includes higher emissions. It will also take longer for the country to meet their NDCs, assuming that many countries using or developing offshore wind does so with the intention of achieving a reduced climate footprint. Lastly, it is worth noting that:

1. These averages also includes demo projects. No project, such as the ones marked in orange in Appendix 1, has been exempt when calculating the average installed capacity, in contrast to when creating the graphs showing time distribution or when generating learning curves.
2. Many commercial companies will not be investing in windfarms that are only 350 MW unless they are demo projects. One of the discussions when working in the field this past summer was whether it was worth bothering to develop a new concept and bid on a 400 MW windfarm, or if the lower limit should be set at 800 MW.

Under the assumption that the number of countries opening their seabed to offshore wind energy will keep expanding -especially if its LCOE keeps dropping as quickly as it has over the last few years (IRENA, 2023), the market could potentially experience a shift from developers competing for leases, to leases (or countries) competing for developers (O, Stephenson, personal communication, October 2023). If this happens, it becomes increasingly important for the countries to have policies in place that makes them an attractive market. In addition to political and policy stability as well as market profitability, having a swift and easy process will likely benefit the countries greatly and aid in attracting developers and investors.

5.5. Implications for emerging markets

There are many things that needs to be in place before a country can dive into the offshore wind industry in a good way. First and foremost, there needs to be political agreement on the objectives of adapting offshore wind -is it to reduce their climate footprint and have a cleaner energy production? Is it to lay the grounds for cheaper energy as the LCOE keeps dropping? Are they aiming to build a domestic industry, and what would said industry look like? Should it be mostly focused on producing turbine parts and/or having subcontractors with the right skills? Or is it more favorable to domestic developers, engineers and firms? These are all things a country needs to consider before shaping their offshore wind policy.

Regardless of the objectives with developing an offshore wind industry, policy predictability is vital in attracting investors and developers. Countries that have seen the most success in offshore wind development, such as the UK and Denmark, have benefitted from policies that offer long-term stability and predictability. This includes clear targets for renewable energy contributions, supportive regulatory frameworks, and consistent incentive schemes like CfDs or FiTs. The stability this offers enables firms to conduct strategic planning, it reduces any risk of delays and overall helps ensure that projects are financially viable.

Further, it is essential for countries to establish the necessary infrastructure before initiating the first leasing rounds. This infrastructure includes ports capable of handling the wind turbine components, enough grid capacity as well as enabling grid connectivity and preferably having the technology required for offshore construction available. If this lacks, as was the case in Taiwan, projects may see significant delays and worst-case scenario also an increase in cost. Ensuring that the necessary infrastructure is in place signals to investors and developers that the offshore wind venture is serious and ready to collaborate and support their business.

When it comes to the lease awarding itself, competitive auctions seem to be the most efficient way of allocating the leases. It may take more effort from the local authorities as they are the ones responsible for EIAs, as well as ensuring that there are no conflicts with other industries, instead of outsourcing this to the developer –as Denmark seemingly did under the “open-door” policy. Further, competitive auctions should by definition drive down the price of electricity in the PPAs and reduce the amounts of subsidies needed to build the windfarm. Naturally, bidders in the auction needs to be pre-qualified or similar, to ensure that they do in fact have the capabilities to deliver both on technical requirements and the financial aspect of the bid. As competition increases, the industry as a whole is likely to see innovations that lead to both cost reduction, time reduction and technical improvements. However, for some countries, an "open-door" policy might be a good place to start. This especially rings true if the government lacks the necessary expertise and resources to clear areas for tendering. If a country starts out this way, it is still vital to have a stable policy framework in place, and likely also to have transition plan towards public auctions in the future -again something they would need to be open about to create predictability.

Lastly, it is vital to have the right incentive mechanisms in place to establish a well-functioning offshore wind industry. Without it, it will likely be challenging for developers, at least at this stage, to find viable business cases in the leases announced. There is no right answer as to what the financial incentives should look like -it depends on the domestic electricity market, the consensus in government (remember, stability is key, so agreement should be across parties) and where in the development stages one is. CfDs can be challenging to introduce to an underdeveloped market as described by Do et al. (2022), while having too high FiTs can lead to high electricity prices and a financial burden for either consumers or government, and thereby create discontent and uproar from consumers. Again, predictability is vital, so the incentive mechanisms put in place needs to be thoroughly considered, have wide political agreement and be decided upon after an assessment of the individual country.

6. Conclusion:

The purpose of this thesis has been to analyze and compare the offshore wind tendering processes and policies along with their effects for Denmark, the UK and Taiwan. This has been done through a literature review to understand the policies along with comparing learning curves for the leasing rounds and comparing time distribution for the different stages of establishment for windfarms in the respective countries. There are some uncertainties related to the results, as there are external factors that could distort or influence them. The analysis does show several finds, both for existing markets and for emerging markets, where the most important measure anyone could implement is political and policy stability and predictability.

It is impossible to make global recommendations to implement specific policies, as countries reason for implementing offshore wind, as well as their infrastructure and political readiness will vary greatly. However, from the analysis there have been a few common success factors such as political stability and having the right incentive mechanisms in place. What incentives will be the right ones, will vary depending on political picture and infrastructure. Further, competitive auctions seem to be more efficient in awarding large amounts of capacity and having them constructed the fastest. However, competitive auctions require more resources and experience from the government as they are the ones to find and research the areas before an auction. For some, competitive auctions might be a challenging place to start, and starting off with an "open-door" policy or similar might be a better starting point in certain situations.

The offshore wind market is expanding rapidly, which leads to the assumption that competition will increase as well. Therefore, it becomes ever more important for any country putting up new areas for lease to have the right policies and incentives in place. Because of this, already developed markets can also learn from these findings and would be wise to work to speed up their own processes as well as making sure they remain competitive and attractive as more competitors enter the market.

References:

Aasbøe, T. N. (2021). *Importance of drivers and barriers for V2G?* [Master's Thesis, Norwegian University of Life Sciences]. Brage. https://nmbu.brage.unit.no/nmbu-xmlui/bitstream/handle/11250/2765758/Tamara%20N%c3%b8rreskov%20Aasb%c3%b8e_2021.pdf?sequence=1&isAllowed=y

BBC. (2013, October 29). *Plans for wind test centre off Aberdeen suffers setback*. BBC. https://www.bbc.com/news/uk-scotland-north-east-orkney-shetland-24734205

Baker & McKenzie. (2023, November 30). *Taiwan: Rules for Round 3-2 Offshore Wind Zonal Development Capacity Allocation*. Baker & McKenzie. https://insightplus.bakermckenzie.com/bm/projects/taiwan-rules-for-round-3-2-offshore-wind-zonal-development-capacity-allocation

de Vasconcelos, R. M. d., Silva, L. L. C., González, M. O .A., Santiso, A. M., de Melo, D. C. (2022). Environmental licensing for offshore wind farms: Guidelines and policy implications for new markets. *Energy Policy, 171*, Article 113248. https://doi.org/10.1016/j.enpol.2022.113248

DEA. (2019). *New Danish calls for offshore wind farm tenders: information on the Thor offshore wind farm tendering procedure*. [Pamphlet]. https://ens.dk/sites/ens.dk/files/Vindenergi/offshore_wind_tendet_thor_marketing.pdf

DEA. (2020). *The Danish Energy Agency as a one-stop-shop authority*. Established as regulations. Danish Energy Agency. https://ens.dk/sites/ens.dk/files/Globalcooperation/one-stop_shop_oct2020.pdf

DEA. (2021). *Tender conditions for the establishment of Thor Offshore Wind Farm*. Established as regulation. Danish Energy Agency. https://www.ethics.dk/ethics/publicTenderDoc/bfb4d610-bfa1-4bfe-8808-6deb212e27cb/09f22645-c381-4a17-a7f4-741f32cf3e16/download

DEA. (2022). *OFFSHORE WIND DEVELOPMENT*. Established as regulations. Danish Energy Agency. https://ens.dk/sites/ens.dk/files/Vindenergi/offshore_wind_development_final_june_2022.pdf

Do, T. N., Burke, P. J., Hughes, L., Thi, T. D. (2022). Policy options for offshore wind power in Vietnam. *Marine Policy, 141*, Article 105080. https://doi.org/10.1016/j.marpol.2022.105080

Dodger Bank Wind Farm. (n.d.). *Our History*. Dogger Bank. Retrieved 03.01.2024 from: https://doggerbank.com/our-history/

Energistyrelsen. (2023). *Redegørelse om forløbet frem mod berostillelse af åben dør-ordningen. (2023-1324*) [Statement on the process leading up to appeasement of the open door procedure]. Established as regulations. Danish Energy Agency 2023. https://ens.dk/sites/ens.dk/files/Vindmoller_hav/redegoerelse_om_forloebet_frem_mod_berostillelse_af_aaben_doer-ordningen.pdf

Equinor. (2023, October 19). *World's largest offshore wind farm Dogger Bank produces power for the first time*. Equinor. https://www.equinor.com/news/202310-dogger-bank

Erraia, J., Foseid, H., Śpiewanowski, P.,Winje, E., Wahl, E., S. (2023). *Offshore wind subsidies in the EU, Norway and the US*. (Menon publication no. 51/2023). Retrieved from https://www.menon.no/wp-content/uploads/2023-51-Offshore-wind-subsidy-regimes.pdf

Fernández, L. (2023, November 1). *Capacity of offshore wind turbines in operation and under construction in 2022, by country (in Megawatts).* Statista. https://www.statista.com/statistics/264264/capacity-of-offshore-wind-power-plants-worldwide-2010/

Fjose, S., Andersen, M. L., Bruvoll, A. (2023). *Utvikling i tidsbruk fra lete- og produksjonslisensgis til produksjon starter på norsk sokkel*. (Menon-notat 9/2023) Retrieved from https://files.nettsteder.regjeringen.no/wpuploads01/sites/479/2023/10/Menon-notat-nr-9-2023-003.pdf

Frost, J. (n.d.). *How To Interpret R-squared in Regression Analysis*. Statistics By Jim. Retrieved 16.04.2024 from https://statisticsbyjim.com/regression/interpret-r-squared-regression/

Gao, A. M., Huang, C., Lin, J., Su, W. (2021). Review of recent offshore wind power strategy in Taiwan: Onshore wind power comparison. *Energy Strategy Reviews*, *38*, Article 100747. https://doi.org/10.1016/j.esr.2021.100747

Great Britain Department for Business and Trade. (n.d.). *Offshore Wind*. Department for Business and Trade. Retrieved 08.01.2024 from https://www.great.gov.uk/international/content/investment/sectors/offshore-wind/

GWEC. (2021). *Global Wind Report 2021*. Global Wind Energy Council. Retrieved 07.03.2024 from https://gwec.net/global-wind-report-2021/

Hogan, M. (2021, December 6). *Local content requirements threathen renewable energy uptake*. Peterson Institute for International Economics. https://www.piie.com/blogs/trade-and-investment-policy-watch/local-content-requirements-threaten-renewable-energy-uptake

Hohl, L. K. (2022). *The scalability of floating wind installations in Norway and beyond* [Master's Thesis, University of Stavanger]. Brage. https://uis.brage.unit.no/uis-xmlui/bitstream/handle/11250/3022603/no.uis:inspera:102985146:65036905.pdf?sequence=1

Hossain, Md. M., Georges, J.-P., Rondeau, E., Divoux, T. (2019). Energy, Carbon and Renewable Energy: Candidate Metrics for Green-Aware Routing?. *Sensors, 19*(13), Article 2901. http://dx.doi.org/10.3390/s19132901

IRENA. (2019). *Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects. Executive summary*. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019_summ_EN.pdf?la=en&hash=D07089441987EBABC7F4BED63B62C83820C18724

IRENA. (2023). *Offshore wind energy: Patent insight report*. International Renewable Energy Agency. Retrieved from https://www.irena.org/Publications/2023/Nov/IRENA-EPO-Offshore-Wind-Energy-Patent-Insight-Report#:~:text=According%20to%20IRENA%20statistics%2C%20a,in%20the%20period%202010%2D2022.

IRENA. (n.d.). *Wind Energy*. International Renewable Energy Agency. Retrieved 03.01.2024 from: https://www.irena.org/Energy-Transition/Technology/Wind-energy

IRENA and GWEC. (2023). *Enabling frameworks for offshore wind scaleup: Innovations in permitting*. International Renewable Energy Agency. Retrieved from https://www.irena.org/Publications/2023/Sep/Enabling-frameworks-for-offshore-wind-scale-up

Jansen, M., Beiter, P., Riepin, I., Müsgens, F., Guajardo-Fajardo, V., J., Staffell, I., Bulder, B., Kitzing, L. (2022). Policy choices and outcomes for offshore wind auctions globally. *Energy Policy, 167*, Article 113000. https://doi.org/10.1016/j.enpol.2022.113000

Kubitschek, R., Wang, J., McCatherin, J. (2023, October 6). Round 3.2: Two steps forward, one step back. *European Chamber of Commerce Taiwan*. https://euroview.ecct.com.tw/category-inside.php?id=1680

Kutner, M. H., Nachtsheim, C. J., Neter, J., Li, W. (2005). *Applied Linear Statistical Models* (Fifth ed.). McGraw-Hill Irwin.

Lillebælt Syd. (n.d.). *Forløbet*. Lillebælt Syd. Retrieved 19.01.2024 from https://lillebaeltsyd.dk/forlobet/

MacKinnon, D., Dawley, S., Steen, M., Menzel, M.-P., Karlsen, A., Sommer, P., Hansen, G. H., Normann H. E. (2019). Path creation, global production networks and regional development: A comparative international analysis of the offshore wind sector. *Progress in Planning, 130,* 1-32. https://doi.org/10.1016/j.progress.2018.01.001

Martinsen, T. (2010). *Technology learning in a global – local perspective - the interplay between technology diffusion, niche markets and experience curves* [Doctoral Thesis, Norwegian University of Science and Technology]. NTNU Open. https://ntnuopen.ntnu.no/ntnuxmlui/bitstream/handle/11250/234143/390870_FULLTEXT01.pdf?sequence=1&isAllowed=y

Mayor, B. (2020). Unraveling the Historical Economies of Scale and Learning Effects for Desalination Technologies. *Water Resources Research*, *56*(2), Article e2019WR025841. https://doi.org/10.1029/2019WR025841

MOEA (n.d.). *Four-Year Plan of Promotion for Wind Power*. Established as regulations. Ministry of Economic Affairs, Energy Administration. https://www.moeaea.gov.tw/ecw/English/content/ContentLink2.aspx?menu_id=965&sub_menu_id=1525

Ramirez, L., Fraile, D., Brindley, G. (2021). *Offshore Wind in Europe Statistics 2020*. Wind Europe. Retrieved from https://proceedings.windeurope.org/biplatform/rails/active_storage/blobs/redirect/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcDhDIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--652a2d205034a95011d035451622eca84378db37/WindEurope-Offshore-wind-in-Europe-statistics-2020.pdf

Rentier, G., Lelieveldt, H., Kramer, G., J. (2023). Institutional constellations and policy instruments for offshore wind power around the North Sea. *Energy Policy*, *173*, Article 113344. https://doi.org/10.1016/j.enpol.2022.113344

Reuters. (2024, January 3). *Equinor, BP cancel contract to sell offshore wind power to New York*. Reuters. https://www.reuters.com/business/energy/equinor-bp-cancel-contract-sell-offshore-wind-power-new-york-2024-01-03/

Rustad, M. E. (2024, January 4). *Norges Havvindsatsing kan bli utsatt*. e24. https://e24.no/energi-og-klima/i/P414O0/norges-havvindsatsing-kan-bli-utsatt

Shrestha, H., B. (2022, February 10). Learning curve effects on the Global Variable Renewable Energy Deployment. *Towards Data Science*. https://towardsdatascience.com/learning-curve-effect-on-the-global-variable-renewable-energy-deployment-73d1e28da390

Song, G. (2023). Understanding Taiwan’s offshore wind industry. *Open Access Government, October 2023*, 478-479. https://doi.org/10.56367/OAG-040-10532

Taylor, C. (n.d.). *How to Do Residuals in Excel*. Chron. Retrieved 16.04.2024 from https://smallbusiness.chron.com/residuals-excel-74433.html

TCE. (2019). *Introducing Offshore Wind Leasing Round 4*. [Information Memorandum] The Crown Estate. https://www.thecrownestate.co.uk/media/3379/tce-r4-information-memorandum-print.pdf

TCE. (2023). *Celtic Sea Floating Offshore Wind*.[Information Memorandum] The Crown Estate.

https://downloads.ctfassets.net/nv65su7t80y5/5zR4gHuqxjMG9NOK1LI2Av/643bfa91696be32408e5e2646c16bbba/Information_Memorandum.pdf

Tso, K. (2021, March 8). *How are countries held accountable under the Paris Agreement?*. MIT Climate. https://climate.mit.edu/ask-mit/how-are-countries-held-accountable-under-paris-agreement

White & Case. (2019). *Offshore wind projects: Assessing the environmental impact.* White & Case. Retrieved from https://www.whitecase.com/sites/whitecase/files/offshore-wind-projects-assessing-the-environmental-impact-final.pdf

World Bank (2019). *Going global Expanding Offshore Wind to Emerging Markets*. [Pamphlet]. https://documents1.worldbank.org/curated/en/716891572457609829/pdf/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets.pdf

World Bank (n.d.). *World Bank Group Offshore Wind Development Program*. [Power Point]. https://pubdocs.worldbank.org/en/120581592321163692/WBG-Offshore-Wind-Program-Overview.pdf

Zaiontz, C. (n.d.). *Power Regression*. Real Statistics using Excel. Retrieved 16.04.2024 from https://real-statistics.com/regression/power-regression/

Ørsted. (2023, March 31). *Ørsted takes final investment decision and is ready to build Greater Changhua 2b and 4 offshore wind farms*. Ørsted. https://orsted.com/en/media/news/2023/03/20230331658411.

Appendix 1

The windfarms marked in orange or red are missing either parts of or all information. For most analyses they have therefore been left out. In some instances, they have been given an average.

Leasing rounds Denmark:

Rounds Denmark	Start	Finish	Award Date	Total Time	Standard or Open-Door?	awarded capacity (MW)	Days/MW	cumulative capacity
Middelgrunden (OD)	24.06.1999	19.12.1999	19.12.1999	178	Open-Door	40	4.5	50
Horns Rev 1 (OD)	28.04.1998	15.06.1999	15.06.1999	413	Open-Door	160	2.6	210
Nysted (OD)	30.04.1998	27.07.2001	27.07.2001	1184	Open-Door	166	7.1	376
Samsø (OD)	07.05.2001	13.12.2001	13.12.2001	220	Open-Door	23	9.6	399
Frederikshavn demo (OD)	30.05.2000	16.02.2002	01.02.2002	627	Open-Door	7.6	82.5	406.6
Rønland (OD)	28.06.2002	19.07.2002	19.06.2002	21	Open-Door	17	1.2	423.6
Horns Rev 2	29.10.2004	30.06.2005	29.10.2005	365	Standard	209	1.7	632.6
Rødsand II part 1			31.05.2006	0	Standard	0	#DIV/0!	632.6
Rødsand II part 2	07.02.2008	21.04.2008	06.05.2008	89	Standard	207	0.4	839.6
Sprogø (OD)			29.05.2008	0	Open-Door	21	0.0	860.6
Anholt	30.04.2009	07.04.2010	02.07.2010	428	Standard	400	1.1	1260.6
Avedøre (OD)	30.05.2008	18.11.2008	18.11.2008	172	Open-Door	10.8	15.9	1271.4
Horns Rev 3	18.06.2014	16.02.2015	27.02.2015	254	Standard	407	0.6	1678.4
Vesterhav Syd & Nord	29.04.2016	01.09.2016	12.09.2016	136	Standard	344	0.4	2022.4
Kriegers Flak	01.06.2016	08.11.2016	09.11.2016	161	Standard	605	0.3	2627.4
Nissum Bredning (OD)	04.12.2009	24.11.2016	28.02.2017	2643	Open-Door	28	94.4	2655.4
Thor	25.09.2020	08.11.2021	01.12.2021	432	Standard	1100	0.4	3755.4
Frederikshavn (OD)	18.07.2017	26.10.2022	26.10.2022	1926	Open-Door	72	26.8	3827.4
Aflandshage (OD)	04.10.2016	11.11.2022	11.11.2022	2229	Open-Door	286	7.8	4113.4
Nordsøen 1A	01.07.2024	31.12.2024	31.12.2024	183	Standard	666.7	0.3	4780.1
Nordsøen 1B	01.07.2024	31.12.2024	31.12.2024	183	Standard	666.7	0.3	5446.7
Nordsøen 1C	01.07.2024	31.12.2024	31.12.2024	183	Standard	666.7	0.3	6113.4
Energiøen Bornholm A	01.07.2024	31.12.2024	31.12.2024	183	Standard	1500	0.1	7613.4
Energiøen Bornholm B	01.07.2024	31.12.2024	31.12.2024	183	Standard	1500	0.1	9113.4
Hesselø	01.07.2024	31.12.2024	31.12.2024	183	Standard	1200	0.2	10313.4
Kroegers Flak II	01.01.2025	30.06.2025	31.12.2025	364	Standard	2000	0.2	12313.4
Kattegat II	01.01.2025	30.06.2025	31.12.2025	364	Standard	2000	0.2	14313.4
North Sea Energy Island OWF	01.07.2026	30.06.2027	31.12.2027	548	Standard	7000	0.1	21313.4

Leasing Rounds UK:

Leasing Rounds UK	Round Start	Round Stop	Award Date	Total Time	Standard/Demo	Awarded Capacity (MW)	Days/MW	Cumulative Capacity (MW)
UK Round 1	01.12.2000	28.02.2001	05.04.2001	125	Standard	1,060	0.12	1,064
Beatrice Demo			04.07.2006	0	Demo	10	0.00	6,651
Westermost Rough Re-tend	01.07.2003	15.10.2003	24.05.2007	1423	Standard	210	6.78	6,861
UK Round 2	01.07.2003	15.10.2003	18.12.2008	1992	Standard	5,577	0.36	6,641
Windfarms in Scottish Wate	11.07.2008	10.10.2008	16.02.2009	221	Standard	2,116	0.10	8,977
UK Round 3	26.09.2008	31.03.2009	05.01.2010	467	Standard	23,426	0.02	32,403
UK Round 1 & 2 extensions	18.09.2009	18.12.2009	11.05.2010	236	Standard	1,320	0.18	33,723
UK Demonstration	01.05.2009	01.12.2009	05.08.2010	462	Demo	158	2.92	33,881
UK Demonstration (Hywind)	16.08.2013	31.10.2013	23.11.2013	100	Demo	30	3.33	33,911
Isle of Man	01.02.2014	11.11.2014	11.11.2014	283	Standard	1,400	0.20	35,311
Scotland Demo (Dounreay)			16.03.2017	0	Demo	100	0.00	35,411
Scotland Demo (Kincardine)			20.09.2019	0	Demo	50	0.00	35,461
UK Celtic Sea Demo			19.08.2020	0	Demo	96	0.00	35,557
UK 2017 extensions	31.05.2018	01.08.2019	28.09.2020	851	Standard	3,943	0.22	39,500
UK Round 4	28.01.2021	08.02.2021	08.02.2021	11	Standard	7,980	0.00	47,480
UK Celtic Sea Demo 2			27.07.2021	0	Demo	300	0.00	47,780
Scotwind round 1	05.08.2020	01.02.2021	17.01.2022	531	Standard	26,279	0.02	74,059
Scotwind round 1 clearing	22.04.2022	22.08.2022	22.08.2022	122	Standard	2,800	0.04	76,859
INTOG	10.08.2022	18.11.2022	24.03.2023	227	Standard	5,588	0.04	82,447
UK Celtic Sea	29.02.2024	30.06.2025	30.09.2025	579	Standard	28,714	0.02	111,161

Leasing Rounds Taiwan:

Leasing Rounds Taiwan	Round Start	Round Stop	Award date	Total Time	Standard/Demo	Awarded Capacity (MW)	Days/MW	Cumulative Capacity (MW)
Taiwan Demo	03.07.2012		28.01.2013	210	Demo	237.2	0.89	237.2
Taiwan Selection Round	01.07.2015		30.04.2018	1034	Standard	3,836.0	0.27	4,073.2
Taiwan Transition Round (	01.07.2015		22.06.2018	1087	Standard	1,664.0	0.65	5,737.2
Taiwan Phase 3.1	16.08.2022	30.09.2022	14.12.2022	120	Standard	4,536.0	0.03	10,273.2
Taiwan Phase 3.2	11.03.2024	10.04.2024	30.05.2024	80	Standard	2,900.0	0.03	13,173.2
Taiwan Phase 3.3	15.10.2024	30.03.2025	30.06.2025	258	Standard		#DIV/0!	13,173.2

Danish windfarms used for analysis:

Wind farm	Capacity (MW	Status	Total days	Construction days	Days/MW	Construction/MW	Cumulative country capacity (MW
Vindeby	5.0	Decommissioned	123	123	24.8	24.8	5.0
Tunø Knob	5.0	Operational	273	273	54.6	54.6	10.0
Middelgrunden	40.0	Operational	557	379	13.9	9.5	50.0
Horns Rev 1	160.0	Operational	1678	1265	10.5	7.9	210.0
Rønland	17.0	Operational	2276	195	133.9	11.5	227.0
Samsø	23.0	Operational	670	450	29.1	19.6	250.0
Frederikshavn Demo	7.6	Operational	1097	470	144.3	61.8	257.6
Nysted	166.0	Operational	2041	857	12.3	5.2	423.6
Avedøre	10.8	Operational	520	348	48.1	32.2	434.4
Horns Rev 2	209.0	Operational	1859	1494	8.9	7.1	643.4
Sprogø	21.0	Operational	551	551	26.2	26.2	664.4
Rødsand II	207.0	Operational	992	903	4.8	4.4	871.4
Anholt	400.0	Operational	1588	1160	4.0	2.9	1271.4
Nissum Bredning	28.0	Operational	2981	338	106.5	12.1	1299.4
Horns Rev 3	407.0	Operational	1868	1616	4.6	4.0	1706.4
Kriegers Flak (Denmark)	605.0	Operational	1887	1726	3.1	2.9	2311.4
Vesterhav Syd & Nord	344	Installation unde	2894	2758	8.4	8.0	2655.4
Omø Syd	320	Submitted	610	610	1.9	1.9	2975.4
Lillebælt Syd	160	Submitted	5845	945	36.5	5.9	3135.4
Frederikshavn	72	Contracted	3819	1893	53.0	26.3	3207.4
Thor	1100	Contracted	2658	2222	2.4	2.0	4307.4
Jammerland Bugt	240	Submitted	0	0	0.0	0.0	4547.4
Nordre Flint	160	Submitted	0	0	0.0	0.0	4707.4

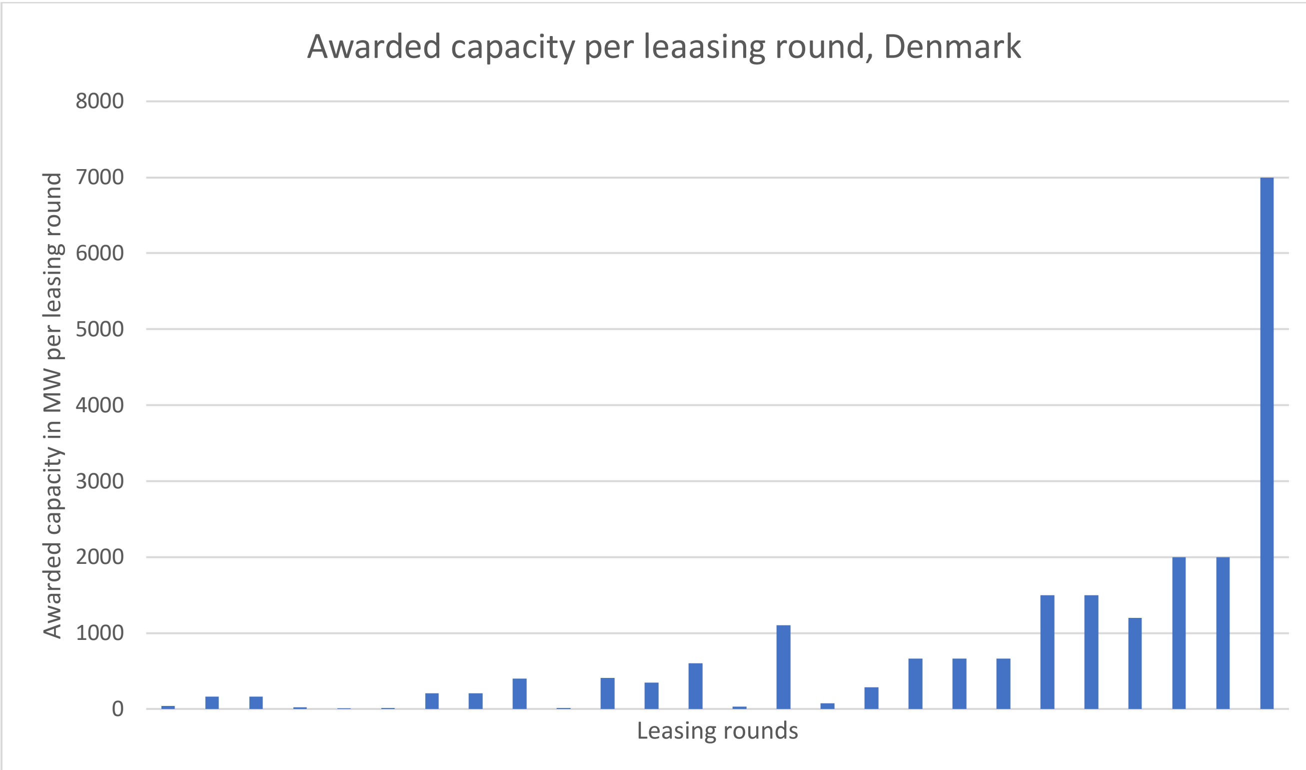
British windfarms used for analysis:

Wind farm	Capacity (MW	Status	Total days	Construction days	Days/MW	Construction/MW	Cumulative Country Capacity (MW
North Hoyle	60	Operational	1217	1092	20.3	18.2	60.0
Scroby Sands	60	Operational	1462	1337	24.4	22.3	120.0
Kentish Flats	90	Operational	1744	1619	19.4	18.0	210.0
Barrow	90	Operational	2100	1975	23.3	21.9	300.0
Beatrice Demo	10	Decommissionec	440	440	44.0	44.0	310.0
Burbo Bank	90	Operational	2512	2387	27.9	26.5	400.0
Lynn and Inner Dowsing	194.4	Operational	3027	2902	15.6	14.9	594.4
Rhyl Flats	90	Operational	3315	3190	36.8	35.4	684.4
Robin Rigg	174	Operational	3408	3283	19.6	18.9	858.4
Gunfleet Sands 1&2	173	Operational	649	649	3.8	3.8	1,031.4
Thanet	300	Operational	2635	637	8.8	2.1	1,331.4
Ormonde	150	Operational	4101	3976	27.3	26.5	1,481.4
Walney 1&2	367	Operational	3203	1205	8.7	3.3	1,848.4
Greater Gabbard	504	Operational	3357	1359	6.7	2.7	2,352.4
Sheringham Shoal	317	Operational	3410	1412	10.8	4.5	2,669.4
Gunfleet Sands 3 (demo)	12	Operational	1449	988	120.8	82.3	2,681.4
London Array	630	Operational	3568	1570	5.7	2.5	3,311.4
Lincs	270	Operational	3677	1679	13.6	6.2	3,581.4
Teesside	62	Operational	4656	4531	75.1	73.1	3,643.4
Levenmouth Demo	7	Operational	1795	1334	256.4	190.6	3,650.4
West of Duddon Sands	389	Operational	4141	2143	10.6	5.5	4,039.4
Humber Gateway	219	Operational	4352	2354	19.9	10.7	4,258.4
Westermost Rough	210	Operational	4348	2350	20.7	11.2	4,468.4
Gwynt Y Mor	576	Operational	4371	2373	7.6	4.1	5,044.4
Kentish Flats Extension	50	Operational	2188	1952	43.8	39.0	5,094.4
Burbo Bank Extension	258	Operational	2779	2543	10.8	9.9	5,352.4
Blyth Demo Phase 1	41.5	Operational	3039	2578	73.2	62.1	5,393.9
Hywind Scotland	30	Operational	1533	1434	51.1	47.8	5,423.9
Dudgeon	402	Operational	5221	3223	13.0	8.0	5,825.9
Rampion	400	Operational	3349	2882	8.4	7.2	6,225.9
Race Bank	573	Operational	5331	3333	9.3	5.8	6,798.9
Galloper	353	Operational	3116	2880	8.8	8.2	7,151.9
EOWDC European Offshor	96.8	Operational	3416	2955	35.3	30.5	7,248.7
Walney Extension	659	Operational	3283	3047	5.0	4.6	7,907.7
Beatrice	588	Operational	1781	1560	3.0	2.7	8,495.7
Hornsea 1	1218	Operational	4268	3801	3.5	3.1	9,713.7
East Anglia One	714	Operational	4324	3857	6.1	5.4	10,427.7
Triton Knoll	857	Operational	6879	4881	8.0	5.7	11,284.7
Moray East	950	Operational	4943	4476	5.2	4.7	12,234.7
Hornsea 2	1386	Operational	5088	4621	3.7	3.3	13,620.7
Seagreen	1075	Operational	5501	5034	5.1	4.7	14,695.7
Neart na Gaoithe (NnG)	448	Installation unde	5835	5614	13.0	12.5	15,143.7
Culzean	3	Lease awarded	876	649	292.0	216.3	15,146.7
Moray West	882	Installation unde	6031	5564	6.8	6.3	16,028.7
Dogger Bank A&B	2470	Installation unde	6307	5840	2.6	2.4	18,498.7
Dogger Bank C	1200	Contracted	6367	5900	5.3	4.9	19,698.7
East Anglia Three	1400	Contracted	6672	6205	4.8	4.4	21,098.7
East Anglia Two	867	Contracted	6672	6205	7.7	7.2	21,965.7
Inch Cape	1080	Contracted	6749	6528	6.2	6.0	23,045.7
Pentland Floating Offshore	100	Lease awarded	0	0	0.0	0.0	23,145.7
Seagreen 1A	500	Lease awarded	6672	6205	13.3	12.4	23,645.7
Sofia	1400	Contracted	1096	1096	0.8	0.8	25,045.7
TwinHub	32	Contracted	0	0	0.0	0.0	25,077.7
White Cross	100	Lease awarded	2164	2164	21.6	21.6	25,177.7
East Anglia One North	602	Contracted	7037	6570	11.7	10.9	25,779.7
Erebus	96	Lease awarded	2691	2691	28.0	28.0	25,875.7
Green Volt	560	Lease awarded	1971	1744	3.5	3.1	26,435.7
Hornsea 3	2852	Contracted	7037	6570	2.5	2.3	29,287.7
Llŷr	100	Lease awarded	2349	2349	23.5	23.5	29,387.7
Llŷr 2	100	Lease awarded	2349	2349	23.5	23.5	29,487.7
Ossian Phase 1	594	Lease awarded	2705	2174	4.6	3.7	30,081.7
Morecambe	480	Lease awarded	2802	2791	5.8	5.8	30,561.7
Cenos	1400	Lease awarded	2337	2110	1.7	1.5	31,961.7
Mona	1500	Lease awarded	2894	2883	1.9	1.9	33,461.7
Morgan	1500	Lease awarded	2894	2883	1.9	1.9	34,961.7
Norfolk Boreas	1380	Contracted	7402	6935	5.4	5.0	36,341.7
Norfolk Vanguard West	1380	Contracted	7402	6935	5.4	5.0	37,721.7
Salamander	100	Lease awarded	2337	2110	23.4	21.1	37,821.7
Awel y Môr	1100	Lease awarded	4233	3382	3.8	3.1	38,921.7
Caledonia	2000	Lease awarded	3436	2905	1.7	1.5	40,921.7
Ossian Phase 2	1008	Lease awarded	3435	2904	3.4	2.9	41,929.7
West of Orkney	2000	Lease awarded	3436	2905	1.7	1.5	43,929.7
Bellrock	1200	Lease awarded	3801	3270	3.2	2.7	45,129.7
Berwick Bank	4150	Lease awarded	8133	7666	2.0	1.8	49,279.7
Buchan	960	Lease awarded	3801	3270	4.0	3.4	50,239.7
Five Estuaries	353	Lease awarded	4598	3747	13.0	10.6	50,592.7
Morven	2900	Lease awarded	3801	3270	1.3	1.1	53,492.7
Muir Mhòr	798	Lease awarded	3801	3270	4.8	4.1	54,290.7
Outer Dowsing	1500	Lease awarded	3625	3614	2.4	2.4	55,790.7
Rampion 2	1200	Lease awarded	4598	3747	3.8	3.1	56,990.7
North Falls	504	Lease awarded	4688	3837	9.3	7.6	57,494.7
Ayre Phase 1	504	Lease awarded	3998	3467	7.9	6.9	57,998.7
Bowdun	1008	Lease awarded	3983	3452	4.0	3.4	59,006.7
Talisk	495	Lease awarded	4105	3574	8.3	7.2	59,501.7
Dogger Bank South - East	1500	Lease awarded	3989	3978	2.7	2.7	61,001.7
Dogger Bank South - West	1500	Lease awarded	3989	3978	2.7	2.7	62,501.7
Flora	50	Lease awarded	3432	3205	68.6	64.1	62,551.7
Malin Sea	96	Lease awarded	3432	3205	35.8	33.4	62,647.7
Ossian Phase 3	1008	Lease awarded	4166	3635	4.1	3.6	63,655.7
Ayre Phase 2	504	Lease awarded	4532	4001	9.0	7.9	64,159.7
CampionWind	2000	Lease awarded	4532	4001	2.3	2.0	66,159.7
MachairWind	2000	Lease awarded	4532	4001	2.3	2.0	68,159.7
MarramWind	3000	Lease awarded	4532	4001	1.5	1.3	71,159.7
Havbredey	1500	Lease awarded	4836	4305	3.2	2.9	72,659.7
Spiorad na Mara	900	Lease awarded	4836	4305	5.4	4.8	73,559.7

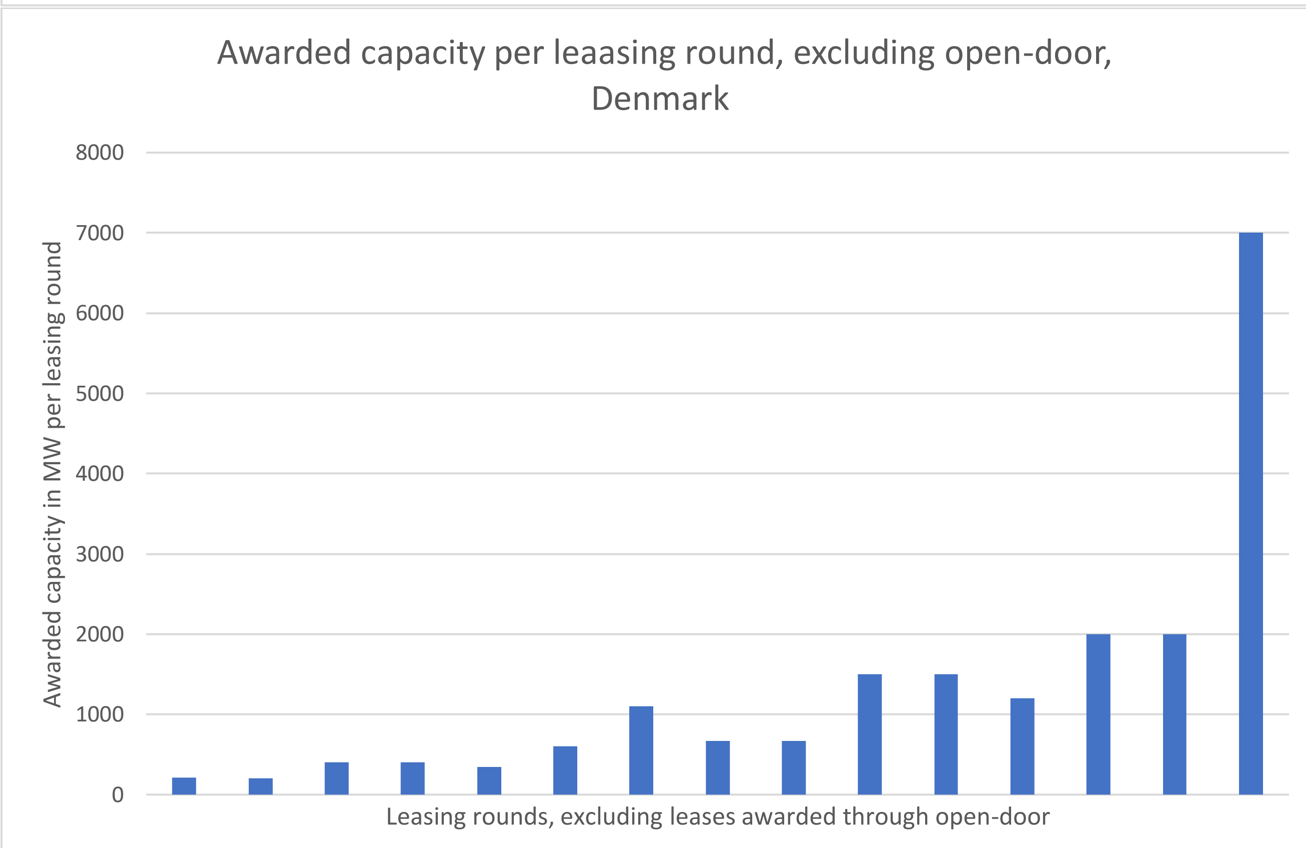
Taiwanese windfarms used for analysis:

Wind farm	Capacity (MW)	Status	Total days	Construction days	Days/MW in	Construction/MW	Cumulative country capacity (MW)
Formosa 1 Phase 1	8	Operational	1551.0	1551.0	193.9	193.9	8.0
Formosa 1 Phase 2	120	Operational	2524.0	2524.0	21.0	21.0	128.0
Taipower Changhua Phase 1 (Demo)	109.2	Operational	3219.0	3219.0	29.5	29.5	237.2
Formosa 2	376	Operational	1904.0	1904.0	5.1	5.1	613.2
Changfang Phase 1 & Xidao Phase 1	100	Installation underway	2109.0	2109.0	21.1	21.1	713.2
Changfang Phase 2 & Xidao Phase 2	500	Installation underway	2109.0	2109.0	4.2	4.2	1213.2
Greater Changhua 1 - SE & 2A - SW	900.2	Installation underway	2109.0	2109.0	2.3	2.3	2113.4
Yunlin YunNeng	640	Installation underway	2385.0	2385.0	3.7	3.7	2753.4
ZhongNeng Phase 1	300	Installation underway	2384.0	2384.0	7.9	7.9	3053.4
Taipower Changhua II	294.5	Contracted	2657.0	2657.0	9.0	9.0	3347.9
Greater Changhua 2B - SW & 4 - NW	920	Contracted	2750.0	2750.0	3.0	3.0	4267.9
Hai Xia	300	Lease awarded	1641.0	1520.0	5.5	5.1	4567.9
Formosa 3 (Haiding 2)	600	Lease awarded	1689.0	1568.0	2.8	2.6	5167.9
Hai Long 2A & 2B & 3	1044	Contracted	3295.0	3295.0	3.2	3.2	6211.9
Da Tian	165	Lease awarded	1965.0	1844.0	11.9	11.2	6376.9
Feng Miao	500	Contracted	1965.0	1844.0	3.9	3.7	6876.9
Formosa 4	495	Lease awarded	1965.0	1844.0	4.0	3.7	7371.9
Jia Neng	500	Lease awarded	1965.0	1844.0	3.9	3.7	7871.9
Wei Lan Hai Changhua	440	Lease awarded	1965.0	1844.0	4.5	4.2	8311.9

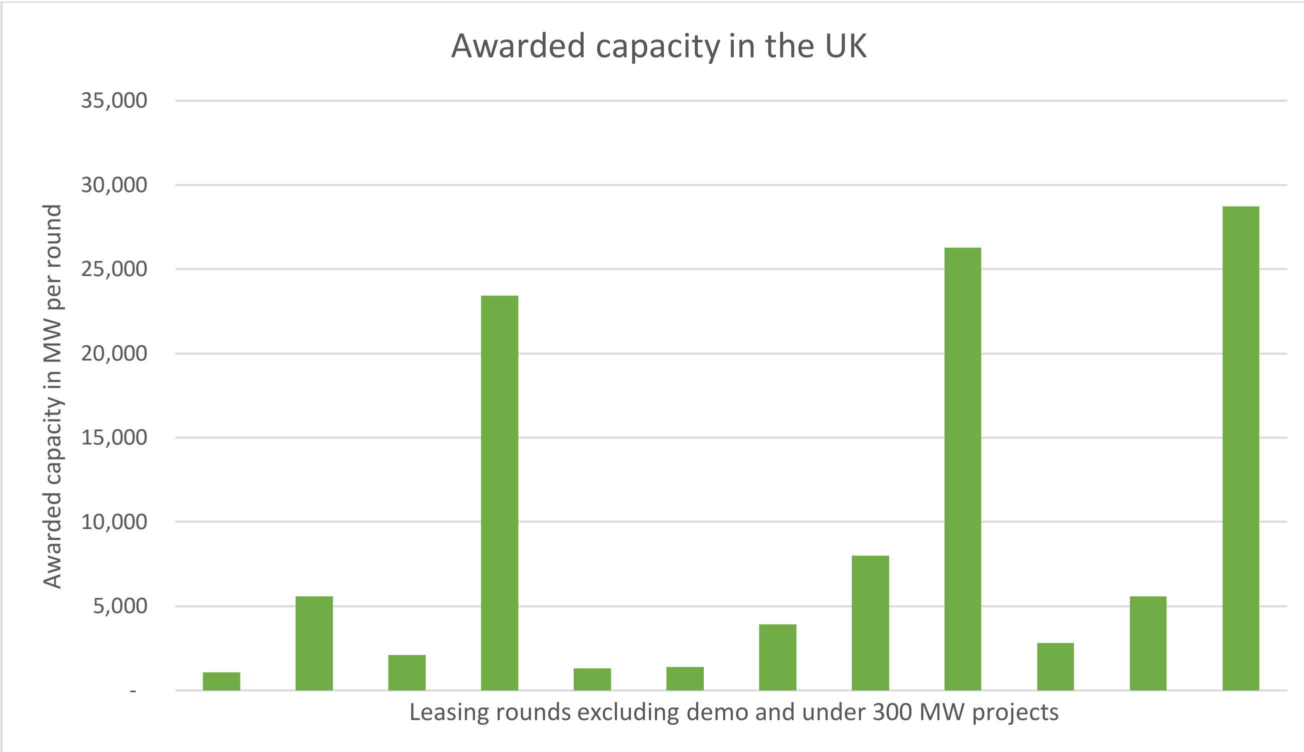
Appendix 2

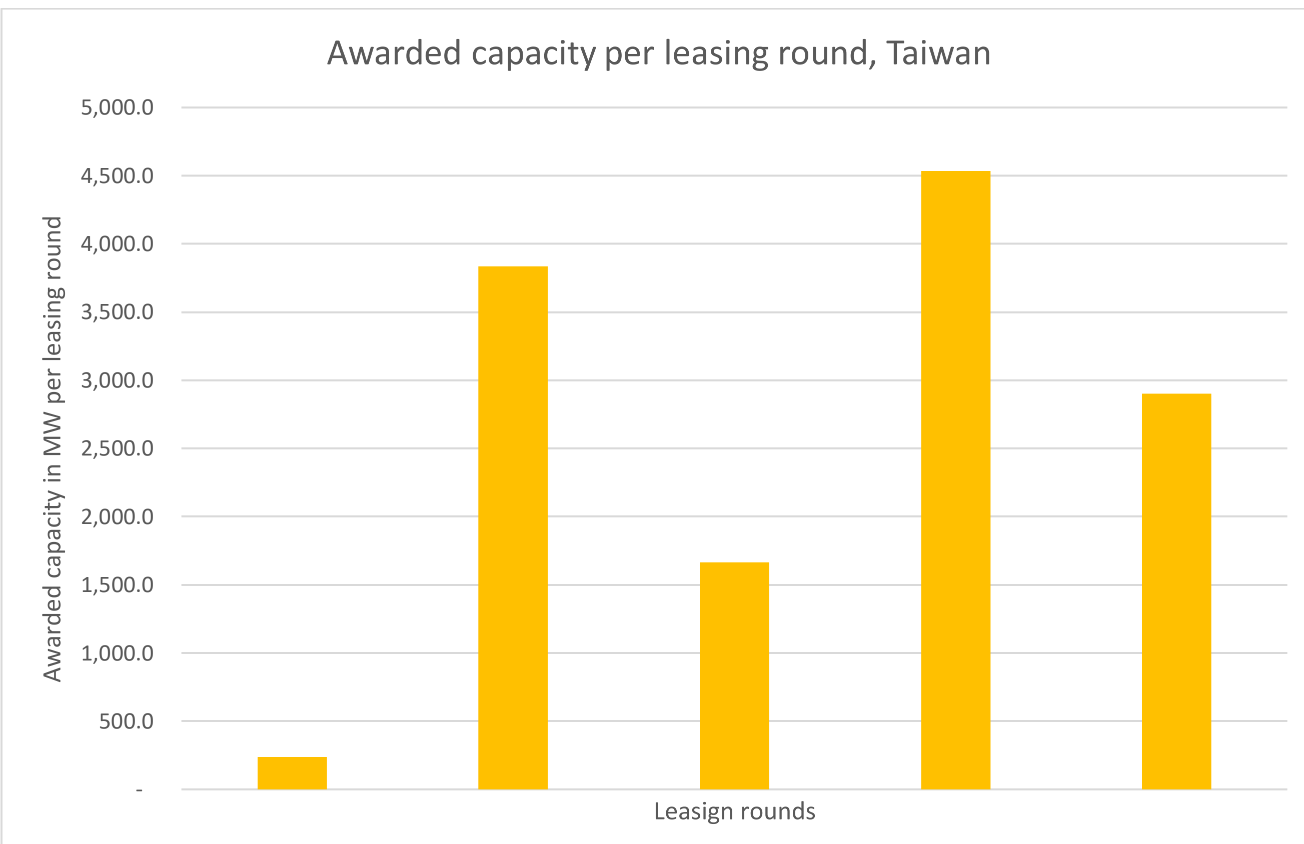


Awarded capacity per leaasing round, Denmark
Awarded capacity in MW per leasing round
8000
7000
6000
5000
4000
3000
2000
1000
0
Leasing rounds



Awarded capacity per leaasing round, excluding open-door, Denmark
Awarded capacity in MW per leasing round
8000
7000
6000
5000
4000
3000
2000
1000
0
Leasing rounds, excluding leases awarded through open-door


Awarded capacity in the UK
Awarded capacity in MW per round
35,000
30,000
25,000
20,000
15,000
10,000
5,000
-
Leasing rounds excluding demo and under 300 MW projects


Awarded capacity per leasing round, Taiwan
Awarded capacity in MW per leasing round
5,000.0
4,500.0
4,000.0
3,500.0
3,000.0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
-
Leasign rounds

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