SCENTIA INTERNATIONAL ECONOMIC REVIEW VOLUME 1 - ISSUE 1 – 2021

The Improvement of Offshore Wind turbine portfolio decisions through cost forecast equations – a qualitative analysis

Maximilian Meißner, Comenius University, Bratislava, Slovakia Michal Gregus, Comenius University, Bratislava, Slovakia

Abstract

In this article we examine the research question 'How cost forecast equations for offshore wind turbine main components can improve the portfolio decisions from Product Portfolio Management (PPM)?" by an extensive literature review of product portfolio decisions within PPM in the wind industry. In addition, two key experts from a leading offshore wind turbine OEM have been interviewed to answer this question and the method of qualitative content analysis as outlined by Mayring has been used to analyze the interviews and interpret the findings. It was analyzed how portfolio decisions for future offshore wind turbines are made and how future turbine costs are estimated. Therefore, this paper provides the scientific foundation by presenting the status quo of how PPM makes portfolio decisions for offshore wind turbines and with it how the future cost of offshore wind turbines are estimated. Aiming to use the presented results in future research to create accurate cost forecast models for the turbine main components and with it the creation of an overall turbine CAPEX scaling model.

Keywords: Product Portfolio Management, Renewable Energy, Portfolio Decision Making, Offshore Wind Turbines, Cost Scaling, Cost Forecast

JEL codes: G11, G17, O13, O32, O33, Q20

1 Introduction

Climate change is real, this is one thing scientists agree on! The average temperature was never higher than in the 20th century and it's still rising. Therefore, in December 2015 the Paris Climate Agreement have been signed by the United Nations Framework Convention on Climate Change. The goal of this pact is to keep the global average temperature below 2°C compared to the 1990ies. To reach this target, the associated states professed to reduce greenhouse gas emissions by the end of the century. Up to 25% in 2040 and 35% in 2050. (IRENA, 2019) Particularly offshore wind turbines, which have several advantages compared to onshore turbines, will drive the progress towards a greener low emission world. As of end of 2020 there is by now around 25.014 MW of constructed offshore wind capacity available. (Jaganmohan, 2021) The forecasts for offshore wind are extremely positive, as offshore wind can compete since 2018 in Europe without subsidies with all conventional energy sources (Alastair Dutton et al., 2019, p. 4). Projections suggest an annual growth from 2019 to 2027 will average 11 GW per year, a fivefold increase over annual installations from the preceding eight-year period.(Alastair Dutton et al., 2019, p. 6) Other sources go beyond and predict for 2030 around 28 GW and 2050 even 45 GW per year. The overall installed offshore wind capacity is predicted to reach 228 GW and up to 1000 GW in 2030 and 2050. This would mean a yearly installation of around 45 GW in 2050 which would be an around ten-fold increase compared to the 4,5 GW added in 2018. (IRENA, 2019) (Meißner, 2020b)

The assumption on which the forecasts are based is that the electricity production costs or levelized cost of energy of offshore wind will continue to decrease. (IEA, 2019) Today, in order to lower the LCOE of offshore wind, one measure by the turbine OEM's is to increase the turbine electrical power rating and the rotor diameter. As this increases the annual energy production and decreases the installation costs per windfarm. In 2020 Siemens Gamesa announced an 14 MW turbine with a 222m rotor diameter (Siemens Gamesa Renewable Energy, 2020). Vestas Wind Systems went one step beyond in 2021 and announced a 15 MW turbine with a 236m rotor (Vestas Wind Systems A/S, 2021). Scientists and researchers predict that turbines will reach 20 MW with rotors of 300 meters in the next decade (Barla, 2019).

But according to the square-cube law the material costs of larger turbines will be significant higher (Huerta, 2006). To avoid this cost increases, innovations and new technologies must be deployed. To offer in the future to the right time the right turbine in terms of size, rating, technology and costs, wind turbine OEM's are using product portfolio management departments.

2 Theory, Research Question and Hypotheses

2.1 Product Portfolio Management

Product Portfolio Management is used since the 1960 and is about the resource allocation for, how to introduce the business's products and technologies objectives (R. G. Cooper et al., 1999; Jugend et al., 2017). Lahtinen et al. (Lahtinen et al., 2019) found in his extended literature research that the main available literature about PPM is focusing on the

management of new product introduction and R&D projects. This is an indication that PPM is mainly focused in the early phases of the product lifecycle process - in the product definition phase (Tolonen et al., 2015). New (Lynn et al., 1999) or updated products will achieve cost reductions and functional improvements which will lead to the company's competitive market position (Hänninen et al., 2013). But PPM is also deciding for the discontinuation of a product (Jugend & Da Silva, 2014). Overall, PPM is impacting with their product and portfolio decisions the long-term growth and financial success of the company and should be based on facts and figures and not on estimations (Mikkola, 2001).

A decision for a product or a whole portfolio is typically made based on business strategy, project risk and product value. Last include the forecast of the estimated material cost of the product. But due to the timing when product portfolio decisions are made, the decision is very complex (R. G. Cooper et al., 1999) as it is next to other reasons very challenging to predict the future cost of a not yet existing product. (Lin, 2007) Mistakes in this early decision making process can lead to poor commercial attractiveness, a transmission of immature technology and higher than expected development expenses (Jugend & Da Silva, 2014). To generate the best portfolio results – a matrix organization with cross functional teams have demonstrated best results (Jugend & Da Silva, 2014; Olson et al., 2001). In addition Cooper et al. already specified in the year 1999 that PPM is using financial models and indices, the option pricing theory and strategic approaches in order to make the right portfolio decision (R. G. Cooper et al., 1999).

The organizational set up of PPM is discussed intensively in the literature. Olson et al. found out that PPM's success is not only limited to cross functional teams between PPM and R&D as it was in the main literature published which he analyzed. He pointed out that operations and marketing also play a key role in the success of PPM's decisions (Olson et al., 2001). Further also Jugend et al. analyzed the organizational structure of PPM through intensive literature reviews and pointed out that next to cross-functional teams also matrix organizations work for successful integration of new product introduction processes (Jugend & Da Silva, 2014). Brettel et al. added marketing as an important stakeholder in the PPM decision process (Brettel et al., 2011). Procurement as a relevant stakeholder could not be found in the literature.

2.2 Cost predictions methodology Offshore Wind Turbines within PPM

As besides others Cooper et al. mentioned already 1999, PPM is responsible for making portfolio decisions and this includes to predict the future cost of the products. For this over 77 % of businesses PPM's teams are using e.g. financial models (R. G. Cooper et al., 1999; R. Cooper et al., 2001). In order to calculate the expected commercial value of a new project the future income stream needs to be predicted, which includes the future material costs of the product (R. Cooper et al., 2001). There are no publications available about how PPM organizations at offshore wind 0EM's are estimating the future cost. But as it is a common sense to use the levelized cost of energy as a reference (BEIS, 2019; Bosch et al., 2019; Bruce Valpy et al., 2017; Crabtree et al., 2015) which will be assumed as a baseline for cost predictions at offshore wind suppliers PPM teams.

Beis et al. defined the LCOE, which is commonly used, as the discounted sum of costs over lifetime divided by the discounted sum of energy produced (BEIS, 2019). Within the discounted sum of costs over lifetime, the turbine costs which includes the nacelles,

towers and blades, represents up to 45 % of whole wind farm CAPEX investment (Brian Snyder & Mark J. Kaiser, 2008; Crabtree et al., 2015; IRENA, 2019; Ove Arup & Partners Ltd). Offshore wind OEM PPM need to predict these costs around four years ahead of serial production. Research showed that there are no accurate cost models available to predict the future CAPEX of offshore wind turbines. This could lead to no commercial attractiveness for the new products. As with increased size of offshore wind turbines, compared to the OPEX-, the CAPEX-portion within the LCOE increases, and with it the need for an increased accurate cost prediction (Meißner, 2020a).

Through this offshore wind OEM PPM is forced to increase the accuracy of the forecast of material costs. But as the literature proved, the current published CAPEX forecast models are not accurate enough (Meißner, 2020a).

3 Methods

3.1 Research question and hypothesis

The literature review about the theory of PPM and wind turbine cost estimation methodology was used as a baseline for the used interview questionnaire. This research paper aims to analyze the current procedure and discover the key decision factors of product portfolio decision making within an offshore wind turbine OEM to close the discovered research gap.

With this the study within this paper is built around the research question, which guides through the research process.

R: How are portfolio decisions made for offshore wind turbine components?

To answer this question this paper is analyzing three hypothesizes.

H1: Financial models are used to calculate the expected commercial value which triggers the portfolio decision.

H2: The LCOE is used as a main decision factor.

H3: Future material cost predictions are made with the help of financial models.

Aim of this research is to present the current procedure of product portfolio decision making within an offshore wind OEM with a clear understanding of the driving decision points. Special attention is paid to the future material cost predictions for offshore wind turbine main components within the decision-making process.

3.2 Research design and strategy

In this type of research, the investigator concludes the significance of his findings and aim to generalizable conclusions. The research was carried out by analyzing literature, interviewing experts of a wind turbine OEM, as well as internal document analysis.

The study was started by carrying out a literature review to have the necessary understanding on the discussed topics, and to map the existing practices and knowledge, regarding product cost estimations for offshore wind turbine components and CAPEX. This part was published in earlier research by the author (Meißner, 2020a). The literature

review was conducted by key word searches on google scholar to search for articles relevant for the topic. The used key words relate to and include several variations of the product portfolio decision process, LCOE, wind turbine costing, cost estimation and forecast. Identified documents and articles were precisely studied to evaluate the applicability.

The presented research question with it hypothesizes will be answered using a qualitative research design with semi-guided expert interviews. The results and insights of the conducted literature review was a key input for the creation of the interview questionnaire to support the interviewer. Answers were categorized and assigned to the predefined hypothesizes to answer the research question. This theory building approach explores theory building blocks from material in a predominant inductive process (Mayring, 2010).

3.3 Data collection

The data collection includes two semi-structured expert interviews with wind turbine OEM employees who holds deep expert understanding and are responsible for the future product portfolio including the material cost prediction. The experts were seen to hold the relevant knowledge on the studied issues, and to enable analyzing the current practices and situation. Each interview was recorded to ensure a detailed examination of the interview. The selected employees included people from an offshore wind OEM PPM organization.

The titles of these people include: Head of Wind Offshore Portfolio Management and Commercial Director Offshore Portfolio Management and Cost Competitiveness.

The interviews have been conducted via Microsoft Teams in a one-on-one setting and lasted 39 and 42 minutes. Interviewers have been at their private places. During the interview, the interview guide was used, varying the sequence of questions according to the respective interview partners, and the selection of questions was adapted individually according to the course of the conversation. This made it possible for the interview to take place as naturally as possible, which was intended to provide the most realistic possible picture of the interviewees' opinions. The interview partners were not aware of the questionnaire to be able to answer the questions more spontaneously and unprepared. The interviews were recorded through the recording function in Microsoft Teams. Following the interviews, they were transcribed in using a transcription software.

3.4 Data analysis

The statements obtained in the expert interviews were converted into text form using the easytranscript transcription software.

The complete transcriptions of the interviews were subsequently compiled and coded with the aid of a self-created Excel spreadsheet. The formulated codes are based on the research question and hypothesizes and were applied to all interviews. Meaningful, content-related categories were formed using a combination of inductive and deductive procedures. In qualitative content analysis, these categories are described synonymously with variables, characteristics, or characteristic values. Extracting the individual text passages and assigning them to the defined categories enables optimal comparability and

provides an overview of the qualitatively valuable and evaluable text components (Kuckartz, 2016).

The following core criteria formulated by Mayring serve as quality criteria for the qualitative research and evaluation of the results for this work: Procedural documentation, argumentative interpretation safeguards, rule-boundedness, proximity to the object, communicative validation, triangulation (Mayring, 2010).

3.5 About the methodology

First, an analysis of the existing literature was conducted, assessed for relevance, and considered accordingly. For the topic, relevant literature was very rare, as the cost impact of the offshore wind turbine growth have not been investigated extensively. Even not for onshore turbines. The literature review was conducted by key word searches on google scholar to search for articles relevant for the topic. The used key words relate to and include several variations of the product portfolio decision process, LCOE, wind turbine costing, wind turbine cost estimation and forecast. It was a challenge to point out relevant literature as the topic is not well researched till today.

The open-mindedness of the interview partners who were available as experts for this work was particularly surprisingly positive. The challenge of finding a meaningful research unit for the sample, which is otherwise common for qualitative research, therefore does not apply in this case. However, a higher sample number would have the advantage of being able to derive more generally valid statements (Flick, 2019). Additionally, conceivable would be a following, quantitative study, which builds on the results of this work, to support the qualitative results with numbers. The validity is certainly to be considered under restriction, since the data collection method was a random sample, which means that the decision of who to include in the sample was not subject to any elaborated sample planning, but only to the discretion of the author of this work.

During the interview, it proved challenging to ask the individual interviewees identical questions, as the answers and general topics took on a very strong momentum during the conversation. Nevertheless, comparable, or contrastable answers were to emerge at the end for an evaluation of the results without any influence on the part of the interviewer. Thus, answers were intentionally not used in the coding table that did not lead in a target-oriented way to answering the research question.

In retrospect, the author considers the decision for a qualitative research design to be correct. Because fundamentally, the qualitative research design, due to its characteristic openness (Mayring, 2010) not only allowed for a certain depth of topic, but also for answers that surprised, such as "I will expect that innovation on the blades is more relevant than in the electrical drive train" (I1, 83-88, p.9). With a quantitative questionnaire, answers like these would very likely not have been recorded, as the author would not have even considered this answer option. The topic would therefore have been predefined from the outset in a much narrower and more subjective way from the author's point of view.

4 Results

In the following section, the empirical data from the individual interviews are presented as condensed results. For this purpose, the statements of the interview partners are assigned according to the formed categories.

C1 Results: Todays procedure of product portfolio decision making

When it comes to the question of a clear procedure for portfolio decisions, the experts' opinions go in the same direction. It is starting with "segmenting the market" in order "to find representative reference projects" for offshore wind farms (I1, 94-98, p.3). After setting this reference project the OEM's "calculating" (I1, 98-102; p.3) or "model a complete costumer business case" (I2, 92-93, p.3; I1 98-102, p.3). The starting point of the procedure of portfolio decision is from OEM perspective the "external view" (I1, 98-102, p.3) from where they can "backwards calculate different sales prices for different turbine configurations" (I2, 96-101, p.3). Included in this external view is as well the "anticipating" of "of competitor turbines" (I1, 98-102, p.3) in order to ensure the calculated sales price is competitive and will "win against the competition" (I1, 98-102, p.3). Through the anticipated sales price, the OEM is able "to test different turbine configurations" (I1, 94-98, p.3). So, the OEM is calculating the whole reference project from the costumer view which leads to a calculation model where the OEM can test if he should sell a "10MW turbine for 10 Mio. Euro or a 15MW turbine for 15 Mio. Euro" (I2, 107-113, p.3). At the end they want to "see what is bringing the most value to the costumer" (I1, 94-98, p.3).

After modeling the external business case the OEM's calculate their "internal business case" (I2, 107-113, p.3) or "view" (I1, 103-108, p.3) as "every turbine development comes with an investment" (I1, 103-108, p.3) into "R&D, into supply chain" and "into suppliers" (I2, 107-113, p.3). The OEM's see what is the "expected investment business case" (I2, 96-101, p.3) which "strongly depends on (...) the turbines size" (I1, 118-119, p.3) or in other words the configuration. Through this and the expected "number of turbines that you need to sell" over time, the OEM's can calculate each turbine options internal payback or "gross margin" (I1, 103-108, p.3) for the company.

C2 Results: Final decision criteria or factor

Referring to the extensive literature study from Meißner the portfolio will be decided on the offshore turbine which delivers the lowest levelized cost of electricity price or LCOE. In addition, it was found out that the literature implies that with a low LCOE it is meant a low CAPEX or material cost of the turbines. (Meißner, 2020a).

But LCOE as a portfolio deciding factor is "only correct when you're assuming constant revenues" (I1, 139-140, p.4). But referring to the reference project, an OEM and with it the costumer have maybe overall the "same cost" for different turbine options in a wind farm. For example, hundred 10 MW turbines for one billion Euro or just fifty 20 MW turbines for the same cost. But these two options can give the OEM and the project developer "different revenues" and so "strictly speaking LCOE is not the right parameter" (I1, 139-140, p.4). But LCOE is a "Euro per megawatt hour number and everyone has an idea if this is high or low", so with it "it's a quite common KPI" (I1, 139-140, p.4). And as well the annual energy production (AEP) – which is a part of the calculation of the LCOE is used from an OEM perspective as one decision point. As the OEM is trying to create the turbine which

gives the "highest AEP" (I2, 93-95, p.3). But the interviewed are clear and say this is not the final portfolio decision point for the optimal turbine. First, they "usually look at IRR and NPV" (I2, 120, p.3) of the costumer for the reference projects. The "investment KPI's for a customer are always IRR and NPV" (I1, 147-150, p.4) so these "are for sure the right criteria's" (I1, 154-159, p.4). From Internal Rate of Return (IRR) and Net Present Value (NPV) is last "easier to understand (...) because that's a million-dollar KPI and not a 0. whatever percent" KPI (I1, 168-170, p.4). But as both are investment KPI's from the costumer point of view, "at the end it's really the costumer business case that counts" (I1, 126-128, p.3).

Regarding the material costs of the OWT's the interviewed "don't think that CAPEX is the major issue" (I1, 180-189, p.4-5) as in the current market situation investment capital is to very cheap conditions available. Especially when investors "have a good risk structure" (I1, 180-189, p.4-5). This means they buy from OEM's turbines where the manufacturer "guarantees" that they "can fulfill (...) obligations" (I1, 180-189, p.4-5). With it the interviewed intended to say that OEM's give warranties for their product and pay in case of failure or breakdown of the product. Regarding the question if the material cost is a portfolio deciding factor, they say that they don't agree fully as for example just "a little bit cost-in create more AEP and that might actually be a good case" (I1, 124-126, p.3).

The costumer business case with NPV and IRR is at the forefront of the portfolio decision and only then the OEM's internal financial KPIs. But "beyond the purely financial view" of the OEM "there is always the risk view which is not quantified" (I1, 197-203, p.5). That means the higher uncertainties for new technologies in new products will lead to higher warranty accruals. In order to make the final portfolio decision the OEM "need to take a decision whether a certain additional value or gross margin" of one product with new unproven technologies "potentially justifies an additional risk" (I1, 223-227, p.5). This balance the OEM need to find. For example, between a cheaper product with proven technology and less risk but fewer output in energy production or a larger, more expensive turbine with higher output but also a higher technology risk structure. With this, the OEM "always consider what is the biggest (...) technical feasibly turbine (...) and calculate that against let's say more moderate steps to find what is the optimum for the next step" (I2, 64-68, p.2) in the portfolio.

C3 Results: Material cost estimation procedure

In the scope of the internal business case creation and portfolio decision, PPM must predict the future material costs of the different options of the turbines. Which is a challenge for the PPM organization in the scoping phase as they "have basically a new configuration idea every day" (I1, 274-280, p.6-7). This is a challenge as PPM "cannot really go for supplier quotes" (I1, 274-280, p.6-7) for each main component to this early scoping phase. First when the organization is coming closer to a final configuration "the more effort you can spend into the cost scaling and the more effort you need to spend" (I1, 274-280, p.6-7) for precise cost estimations. So, the "first early predictions are based on simple (...) scaling" (I2, 174-186, p.4-5). For this, the PPM organization is "breaking it down to the most relevant components" (I1, 317-318, p.7) also main components called. PPM "cannot do that on Nacelle level (...) that doesn't work" (I1, 322,329, p.7-8). Reason is that different parts "scale different (...) and you really need to look into the details" (I1, 322,329, p.7-8). As the cost drivers can be the torque or other forces which drives the weight of components. For the costing, PPM is defining the dimensions and characteristics for the

main components of the different turbine options. With that PPM and the technology development department is performing load calculations and see how for example the weight of the casting components is increasing. So, on these parts PPM is performing "some basic scaling on that (...) with euro per kilogram". For blades they also perform a euro per kilogram scaling but in addition PPM is scaling "at the surface area" but it's just "a real basic scaling what you can do" (I2, 174-186, p.4-5). The cost estimations for the electrical systems are based on simple scaling per megawatt, "so basically output driven" (I2, 191-194, p.5). An expert mentioned "there are so many different things (...) component by component what is driving the costs" (Meißner, 2020c), 280-286, p.7).

But one important point was mentioned that PPM is "not looking how the absolute cost changes but more how does the rational or the difference between two turbines change" (I2, 300-301, p.7). This is at the end what goes into the final business case for each turbine configuration. After the configuration is set, PPM is performing some more detailed cost estimations with cross functions like Industrial, "Technology and Cost Value Engineering from Procurement. So, involving the different experts" (Meißner, 2020d)201-211, p.5).

5 Discussion

At this point, a discussion of both the content should take place to be able to answer the research questions. This will be done through interpretation of the results and with the help of the literature. The discussion of the content refers to the critical reflection of the statements of the interview partners in the context of theory and research. The methodological discussion has been discussed already in the methods part and refer to the selection of the chosen interview partners and the procedure within the framework of the research design.

At this point, the results will be interpreted and evaluated. For this purpose, the research question will be answered by answering and discussing the hypotheses. The overarching research question is "How are portfolio decisions made for offshore wind turbine components?". To answer this question this paper is analyzing the three hypothesizes with the help of the build categories.

H1: Financial models are used to calculate the expected commercial value which triggers the portfolio decision.

The research proofed that the portfolio decision procedure is a very complex but in addition individual process. This is indicated through the individual choice of a reference project as a basis for a portfolio decision. This choice might already differ between OEMs which would lead to a conclusion that OEM's use different data for their business case calculation models. What has come in addition to light through the research is that OEM's try to calculate the highest possible sales price. This sales price is then set for the internal business case calculation and to comparing different portfolio options until a final decision is taken. However, this calculation includes many uncertainty factors such as the estimate of the cost and size of the competitor turbines as well as the target margin and financing conditions for the project developer. But through the research it is proved that the portfolio decision through offshore wind PPM is mainly driven by the fact to win against competition. And the commercial value of a product is just the second important factor. This was mentioned by all interviewed persons that first the external view or

costumer business case is considered. And just second the internal view or internal business case calculation, which includes the portfolio decision.

The hypothesis can be answered that the calculated commercial value triggers the portfolio decision. But the customers business case calculation is the baseline and main priority to win against the competition. The used financial models can't be generalized as the data and baseline assumptions can differ from one to another OEM. Further research must be performed to compare different internal financial calculation models.

H2: The LCOE is used as a main decision factor.

Until this research literatures common sense was to use the LCOE as a main decision factor for offshore wind product portfolio decisions. (Meißner, 2020a) That meant the turbine which delivers the lowest LCOE would be chosen by the OEM. But this research proved that this is only partially true. As it was found out that different turbine configurations can deliver the same LCOE but different revenues for OEM's and customers. LCOE is the widely used factor as it is an easy to understand Euro per MWh financial indicator according to the interviewees. But as the results from H1 already outlined, OEM's commercial value is only second important factor. Main factor is the costumer or project developer's business case. This is also confirmed by the interviewees which are in common sense that the IRR and NPV are the main decision factors for the final turbine choice. This is an important finding as this indicates the fact that the offshore wind market is a buyers' market. But to draw this conclusion further research must be undertaken.

Further it was found out that the CAPEX of a wind farm and with it the material costs of the turbines is not the limiting or deciding factor for PPM's portfolio decision. This has two reasons. First, that costumers and project developers can finance their project to very cheap conditions. And second, bigger turbines to higher costs can generate more electricity and could over lifetime significantly improve the business case for the costumer.

This research laid out, next to the NPV and IRR, another important decision factor. The risk factor for new technologies which are according to the interviewees difficult to quantify. But new unproven technologies could improve the business cases for both, the OEM and costumer. And so, the OEM is calculating their internal and the costumer's business case with additional warranty accruals.

To answer H2 it can be said that the LCOE is not the main decision factor for the portfolio decision of an offshore wind turbine OEM. But parts of the LCOE equation, e.g. the AEP, are still considered to a later stage whereas CAPEX, on the other hand, plays a secondary role. This paper presented that the costumers IRR and its complement the NPV are the main decision factors for offshore wind OEM's to make their future turbine choice. And in addition, an additional technology risk-KPI was presented as a second main decision factor for the final choice of turbine option.

H3: Future material cost predictions are made with the help of financial models

In the process of offshore wind turbine portfolio decision, the PPM organization needs to predict the future material costs. This estimation needs to be done for the different turbine options for the internal and external business cases. Interviewees confirmed previous research which indicates that in order to estimate the turbine overall costs, PPM is scaling the cost on main components (Meißner, 2020b). This research laid out that the

cost of different sub-components is calculated or scaled in a very simple way. The weight driven components, e.g. the blade, are scaled on a Euro per Kilogram basis with today's commodity prices. On the other hand, the electrical components are scaled per megawatt output. For example, a transformer of a 10 MW turbine which costs $500.000 \in \text{will}$ be estimated for a 20 MW turbine with $1 \text{mio} \in \mathbb{R}$.

The interviewees elaborated that the cost estimations of sub-components are done with the help of cross-functions like development and procurement departments. But the interviewees also laid out that this approach will start to a later stage when the turbine choice is mainly taken. After the final decision has been taken, the cross functions are discussing different main components with suppliers to receive well-founded cost estimates.

To answer H3 it can be clearly said that the material costs are not calculated through financial models or with special cost scaling equations. The cost estimations for the business case calculations are done via very basic scaling methods and the best guess of internal individual employees and experts.

R: How are portfolio decisions made for offshore wind turbine components?

The summary of H1 laid out that the portfolio decision making process is an internal procedure with several steps (Figure 1). First, wind OEM's PPM is defining a reference offshore wind farm project. Subsequently building a costumer business case for this reference project with the result of a possible OEM's sales price. This, from OEM perspective, external business case includes besides other assumptions like financing costs, electricity prices and cost and performance of competitors future turbines. Main decision factors are the IRR and NPV for the costumer (H2). The determined sales price for a turbine option is used for the internal business case calculation. PPM is checking if the new future turbine option can meet the calculated sales price including a target profit margin. For the internal business case the main decision factors are the annual energy production and the risks of new technology introduction. The turbine material cost (CAPEX) plays a secondary role (H3) which is contradicting what literature is outlining. This must be further be researched. In addition, it has been noticed that the material cost of the wind turbine is estimated manually with high dependency on human expertise and without data management. Through this, the risk of inaccurate CAPEX estimations is high.

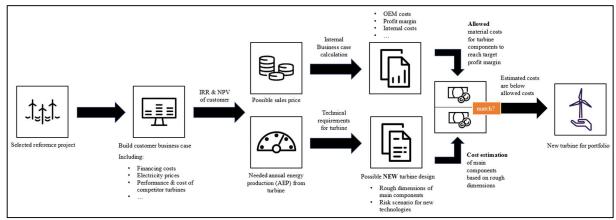


Figure 1: Portfolio decision process at an offshore OEM. How a decision for the final turbine design is made.

6 Conclusion and outlook

The research objective of the present research paper was to use a qualitative research design with the help of expert interviews to outline the procedure of product portfolio decision making within an offshore wind turbine OEM. This paper presented the actual portfolio decision-making process with key decision factors. It was also outlined how material costs are estimated within the current procedure. The picture that can be drawn from the literature analysis and the evaluation of the expert interviews is surprisingly clear and not as expected. LCOE is only a part of the decision-making process but not the main decision factor as it was assumed in the literature before this research. In this case it looks like that the industry is further in their development as the literature. One possible explanation can be that the offshore wind industry is a rather young industry and not yet well researched. This paper contributes to close a portion of the research gap.

Another point which is contradicting with the literature is the importance of CAPEX in the decision-making process. Especially for larger future offshore wind turbines this must be further be researched.

The results and findings of this work should be confirmed and further be researched as recommended through a quantitative research with industry wide experts. With this further research, the diversity of the group of experts can be increased too.

7 Limitations

This study faces several methodological and conceptual limitations. Looking at the conceptual design, this study lay out an incremental insight into the product portfolio decision process of a product portfolio management organization within an offshore wind OEM. Nevertheless, it would be worth to add additional internal stakeholders, like sales, procurement, and R&D.

From the methodological site, it was already mentioned that the research could be extended to a higher sample size to be able to derive more generally valid statements for the research questions. Even though no substantial informant bias was found in the answers, using multiple interviewees and/or further objective criteria might be beneficial. Additionally, the author suggest a following, quantitative study, which builds on the results of this work, to support the qualitative results with numbers.

The validity is certainly to be considered under restriction, since the data collection method was a random sample, which means that the decision of who to include in the sample was not subject to any elaborated sample planning, but only to the discretion of the author of this work. In addition, the experts work for the same turbine OEM. As a result, the sample is biased and not representative, because the experts selected in this way do not represent a cross-section of the industry.

Therefore, further research should include industry-wide experts from Product Portfolio Management of different wind turbine OEM's. Furthermore, the research question has been answered and tested with interviewees with only one nationality, this indicates the likelihood of cultural bias. It is recommended for the empirical evidence to broaden the data collection and interviewer partners with a more cultural diversity.

Acknowledgment

This paper is an output of the science project at the leading offshore wind turbine OEM. It received no funding's from external parties. The author is grateful to the anonymous reviewers for their insightful and detailed comments, which have significantly improved this paper.

References

- Alastair Dutton et al. (2019). *Going-Global: Expanding-Offshore-Wind-To-Emerging-Markets.* The world Bank.
 - http://documents.worldbank.org/curated/en/716891572457609829/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets
- Barla, S. (2019). *Next-Generation wind turbine models*. https://www.woodmac.com/reports/power-markets-next-generation-wind-turbine-models-2019-328241
- BEIS. (2019, May 22). *Electricity Generation Cost Report*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/566567/BEIS_Electricity_Generation_Cost_Report.pdf
- Bosch, J., Staffell, I., & Hawkes, A. D. (2019). Global levelised cost of electricity from offshore wind. *Energy*, 189, 116357. https://doi.org/10.1016/j.energy.2019.116357
- Brettel, M., Heinemann, F., Engelen, A., & Neubauer, S. (2011). Cross-Functional Integration of R&D, Marketing, and Manufacturing in Radical and Incremental Product Innovations and Its Effects on Project Effectiveness and Efficiency. *Journal of Product Innovation Management*, 28(2), 251–269. https://doi.org/10.1111/j.1540-5885.2011.00795.x
- Brian Snyder, & Mark J. Kaiser (2008). Ecological and economic cost-benefit analysis of offshore wind energy. Advance online publication. https://doi.org/10.1016/j.renene.2008.11.015
- Bruce Valpy, Giles Hundleby, Kate Freeman, Alun Roberts, & Andy Logan. (2017). Future renewable energy costs: Offshore wind: 57 technology innovations that will have greater impact on reducing the cost of electricity from European offshore wind farms.
- Cooper, R., Edgett, S., & Kleinschmidt, E. (2001). Portfolio management for new product development: results of an industry practices study. *R&D Management*, *31*(4), 361–380. https://doi.org/10.1111/1467-9310.00225
- Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (1999). New Product Portfolio Management:: Practices and Performance. *The Journal of Product Innovation*

- *Management.* Advance online publication. https://doi.org/10.1111/1540-5885.1640333
- Crabtree, C. J., Zappalá, D., & Hogg, S. I. (2015). Wind energy: UK experiences and offshore operational challenges. *Proceedings of the Institution of Mechanical Engineers, Part a: Journal of Power and Energy, 229*(7), 727–746. https://doi.org/10.1177/0957650915597560
- Flick, U. (2019). *Qualitative Sozialforschung: Eine Einführung* (9. Auflage, Originalausgabe). *rororo Rowohlts Enzyklopädie: Vol. 55694*. Rowohlt Taschenbuch Verlag.
- Hänninen, K., Kinnunen, T., Haapasalo, H., & Muhos, M. (2013). Rapid productisation: challenges and preconditions. *International Journal of Product Lifecycle Management*, 6(3), Article 55877, 211. https://doi.org/10.1504/IJPLM.2013.055877
- Huerta, S. (2006). Galileo was Wrong: The Geometrical Design of Masonry Arches. *Nexus Network Journal*, 8(2), 25–52. https://doi.org/10.1007/s00004-006-0016-8
- IEA (2019). Offshore Wind Outlook 2019. https://www.iea.org/reports/offshore-wind-outlook-2019
- IRENA. (2019). Future of Wind: Deployment, investment, technology, grid integration and socio-economic aspects. https://www.irena.org/publications/2019/Oct/Future-of-wind
- Jaganmohan, M. (2021). *Cumulative offshore wind power capacity installations in Europe from 2006 to 2020*. https://www.statista.com/statistics/271055/cumulative-european-offshore-wind-power-capacity-installations/
- Jugend, D., & Da Silva, S. L. (2014). Product-portfolio management: A framework based on Methods, Organization, and Strategy. *Concurrent Engineering*, 22(1), 17–28. https://doi.org/10.1177/1063293X13508660
- Jugend, D., Luiz, J. V. R., Jabbour, C. J. C., Silva, S. L., Beatriz, A., Jabbour, L. d. S., & Salgado, M. H. (2017). New Product Portfolio Management: Practices and Performance: Empirical Evidence from an Emerging Economy. *Business Strategy and the Environment* (Volume 26, Issue 8), 1181–1195. https://doi.org/10.1002/bse.1977
- Kuckartz, U. (2016). *Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung* (3., durchgesehene Aufl.). *Grundlagentexte Methoden*. Beltz Juventa.
- Lahtinen, N., Mustonen, E., & Harkonen, J. (2019). Commercial and Technical Productization for Fact-Based Product Portfolio Management Over Lifecycle. *IEEE Transactions on Engineering Management*, 1–13. https://doi.org/10.1109/TEM.2019.2932974
- Lin, C.-T. (2007, December). New product portfolio selection using fuzzy logic. In *2007 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 114–118). IEEE. https://doi.org/10.1109/IEEM.2007.4419162

- Lynn, G. S., Abel, K. D., Valentine, W. S., & Wright, R. C. (1999). Key Factors in Increasing Speed to Market and Improving New Product Success Rates. *Industrial Marketing Management*, *28*(4), 319–326. https://doi.org/10.1016/S0019-8501(98)00008-X
- Mayring, P. (2010). Qualitative Inhaltsanalyse: Grundlagen und Techniken.
- Meißner, M. (2020a). Offshore Wind Turbine Cost Scaling: A critical Assesment and theoretical Investigation. In EAB Publishing (Ed.), Essays der Wissenschaft: Akademische Essays aus dem Bereich der interdisziplinären Wissenschaften zur Anwendung in Theorie und Praxis (Teil 19 / XIX) (19th ed., pp. 161–183). Readbox Unipress.
- Meißner, M. (2020b). Offshore wind turbine cost structrue analysis. *High Technology Letters* (Volume 26, Issue 10), 24–38. https://doi.org/10.37896/HTL26.10/1903
- Meißner, M. (2020c, December 18). *Interview I1*. https://doi.org/10.7910/DVN/FP5RCW
- Meißner, M. (2020d, December 21). *Interview I2*. https://doi.org/10.7910/DVN/FP5RCW
- Mikkola, J. H. (2001). Portfolio management of R&D projects: implications for innovation management. *Technovation*(Volume 21, Issue 7), 423–435. https://doi.org/10.1016/S0166-4972(00)00062-6
- Olson, E. M., Walker, O. C., Ruekerf, R. W., & Bonnerd, J. M. (2001). Patterns of cooperation during new product development among marketing, operations and R&D: Implications for project performance. *Journal of Product Innovation Management*, 18(4), 258–271. https://doi.org/10.1111/1540-5885.1840258
- Ove Arup & Partners Ltd. *Review of Renewable Electricity Generation Cost and Technical Assumptions*.

 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/566718/Arup_Renewable_Generation_Cost_Report.pdf
- Siemens Gamesa Renewable Energy. (2020). *Powered by change: Siemens Gamesa launches 14 MW offshore Direct Drive turbine with 222-meter rotor* [Press release]. https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/newsroom/2020/05/siemens-gamesa-press-release-turbine-14-222-dd-en.pdf
- Tolonen, A., Shahmarichatghieh, M., Harkonen, J., & Haapasalo, H. (2015). Product portfolio management Targets and key performance indicators for product portfolio renewal over life cycle. *International Journal of Production Economics*, *170*, 468–477. https://doi.org/10.1016/j.ijpe.2015.05.034
- Vestas Wind Systems A/S. (2021). *Vestas launches the V236-15.0 MW to set new industry benchmark and take next step towards leadership in offshore wind.* https://mb.cision.com/Public/18886/3283489/a42e3f67f111dd1e.pdf