



Performance-based maintenance contracts for offshore wind farms

*A decision-making flowchart to structure the sourcing process for
the post-warranty O&M phase of offshore wind farms*

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*A decision-making flowchart to structure the sourcing process for
the post-warranty O&M phase of offshore wind farms*

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Colophon

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*‘...As yet, the wind is an untamed, and unharnessed force;
and quite possibly one of the greatest discoveries hereafter to be made,
will be the taming, and harnessing of it.’*

Abraham Lincoln (1860)

Preface

This thesis is part of a graduation project for the MSc Construction Management and Engineering at Delft University of Technology. During the master program, I developed a keen interest in renewable energy technologies, which led me to write my thesis about offshore wind energy.

Combining the knowledge from coursework with my personal interests shaped the topic of this research, involving asset management, process management and contracting. KPMG Advisory has expertise in these fields and provided me with the opportunity to write my thesis in cooperation with the Shared Services & Outsourcing team.

Furthermore, I am grateful to KPMG Advisory for the warm welcome I received and excellent support throughout the project. In particular, I would like to express my gratitude to Jort Meijer for his efforts, feedback, and coaching throughout the process. Jort took time to listen, guide me and keep me on track. Besides, he introduced me to several industry leaders, which greatly benefitted my research. Furthermore, I would also like to thank all colleagues at the department of Shared Services & Outsourcing, KPMG, who were always prepared to help, listen and share their opinions. Moreover, I thank my close colleagues from the Procurement team for being part of the team that supported me through the whole process.

Next to my graduation committee, I thank everyone who contributed to the content of this research; firstly, all interviewees who shared their knowledge and their perspective on the developments in the offshore wind industry and on performance-based contracting for heavy assets. Secondly, I wish to say thank you to the two wind farm owners who introduced me to the sourcing approach for their offshore wind farms, which helped me picture the real-life operation and maintenance sourcing process. I was welcome to the port of Ijmuiden to see the offshore wind turbines from a close distance and to get a feeling of the day-to-day operational tasks of the owner and the original equipment manufacturer. This visit contributed strongly to my interest and understanding of the offshore wind industry.

Last but not least, I thank my family and friends for all the support in this last phase of my master. This journey would not have been possible without you.

J.W. (Janneke) Schaeken

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Executive summary

The pioneers in the early 21st century who built the first big offshore wind farms now have to compete with the quickly improving renewable energy technologies and see their farm being out-dated. (See also: Dvorak (2013) & Wind Energy Update, 2013). To create a stronger position in the energy market, the post-warranty sourcing strategy of offshore wind farms needs to guarantee innovation in new technologies and a reduction of the levelized cost of energy (LCOE).

At present, wind farm owners face difficult decisions when finding the right Operations & Maintenance (O&M) contract for their offshore wind farm after the warranty period with the original equipment manufacturer (OEM) has ended. Because of a lack of experience in this new operation and maintenance phase, decision-making processes are not yet structured or standardized (Wind Energy Update, 2013).

The O&M costs of offshore wind contribute substantially to the total LCOE of wind energy (Milborrow, 2010). When the LCOE of wind energy remains high compared to the LCOE of the oil & gas industry and when a high innovation level is not guaranteed, the transition towards renewable energies will not evolve fast enough.

During the warranty period of approximately 5-10 years, traditional performance-based contracts based on availability guarantees are offered by the turbine manufacturer (Kraemer, 2017 & Schontag, 1996). The scope of these contracts is crucial. When the scope of the performance contract is not properly defined or bounded, this can increase the risk to one or more of the parties. To stimulate innovation and increase the energy output, some O&M activities may be better off outside the scope of the performance contract and need a different sourcing scenario. This leads to the aim of this research to compose a decision-making flowchart that can be used when finding a new sourcing strategy for the O&M of offshore wind farms in the post-warranty future.

With this decision-making flowchart, wind farm owners will be able to reduce their O&M costs and stimulate efficiency and innovation. The decision-making flowchart needs to function as a roadmap for future sourcing decisions from the owner's perspective.

Thus, the main research question for this research entailed;

How to scope performance-based maintenance contracts for the post-warranty O&M phase of offshore wind farms?

The research starts with a literature study on the O&M activities in the offshore wind industry and possible decision-making variables derived from contract theories. With these variables it attempts to construct a decision-making flowchart using a qualitative and empirical research strategy. With the decision making variables structured in a decision flowchart, the main research question will be answered.

During the literature study, performance indicators and cost drivers of the O&M activities in the offshore wind industry were examined because this is important information when a performance-based contract is preferred. It was concluded that these O&M activities can be segmented in three main items: the offshore turbine maintenance activities, offshore logistics and the onshore back-office maintenance operations. The three main activities all contribute to the general performance indicator 'availability' (which can be segmented into accessibility, reliability, maintainability and condition measurability), yet in a different way.

The offshore logistics contributes mainly to the accessibility of the wind farm, the actual turbine maintenance contributes to the reliability and maintainability of the turbines and all the back-office maintenance operation activities contribute to the reliability and the condition measurability. Increasing the maintenance efforts will improve the overall availability of the wind farm but will also increase the required resources to be devoted to O&M. For this reason, it is important to know the cost-drivers of the main O&M activities.

The location of the wind farm and the weather forecasting are cost-drivers that play the most important role for the accessibility of the wind turbines. Secondly, the risk type items (Gearbox, generator and rotor), the offshore work hours and the heavy equipment are cost-drivers for the maintainability of the wind turbine. The costs for condition monitoring and performance measurement systems are essential to collect and interpret data to

define the reliability of the turbines. These activities and their main cost drivers are in this research combined with the Six Stage model that visualizes all the possible O&M steps within a performance-based maintenance contract.

These insights were combined and used to structure the decision-making tool. The transaction cost theory was used to define the most efficient boundaries of the owners firm. Here the asset specificity, uncertainty and frequency of the transaction are indicators that have an effect on the cognitive and constructive complexity of the transaction. The owners' techniques and processes that are needed to transfer or take in-house a good or service were identified as the 'proprietary nature' which is an important decision variable when choosing between the O&M in-house or outsource option.

Next, when an O&M activity will be outsourced, there is a choice between a traditional behaviour based contract and a performance-based contract. A performance-based contract requires a relatively high level of knowability of the performance compared to behaviour-based contracts. The Six stage model was used to explain the relationship between the performance requirements and the final performance output. The degree of knowability of performance is assessed with agency theory and is the second decision variable.

Also, it was found that the type of contract is influenced by the dynamics of the environment. Within a performance contract, the aim is to keep the asset available according to the agreed performance level and function. If the performance requirements change due to new innovations in a fast changing industry, the performance outcome becomes difficult to measure which has a negative effect on a performance-based contract.

So, the contract theory variables that are relevant in the decision making process for a new sourcing strategy for offshore wind farm O&M are the 'proprietary nature' of the owner, the 'innovation dynamics' of the industry and 'the knowability of the performance' regarding the wind turbines.

Based on these three contract theory variables, the first theory-based flowchart was drafted, consisting of the O&M activities including the cost-drivers and influence on the performance as the input of the flowchart. Subsequently, interviews and two extensive cases studies led to adjustments of the theoretical decision flowchart. Thus, the nature of the research is comparable with a design-oriented research, which offers a constant process of improvement throughout the case studies.

The decision-making options within a performance-based contract for post-warranty O&M of offshore wind farms are all captured in the flowchart that is composed and tested in the cases.

The decision-making options altogether lead to four scenarios that could offer a possible sourcing strategy after the warranty period:

- 1) The Broker Scenario

The Broker chooses for the outsourcing option because there are constructive and/or cognitive complexities regarding the O&M activities, which leads to a low level of proprietary nature. There is information asymmetry and/or a lack of asset specificity. If the performance of the total system can be measured and predicted, a performance-based approach with the OEM can be the future option, but the broker has to be aware of the fact that the activity is not a core activity of the owner, even though it does not include disruptive technologies.

- 2) The Incubator Scenario

There is a low level of proprietary nature from the perspective of the Incubator and there are cognitive and constructive complexities in its dynamic environment. The Incubator is limited in solving complex problems and processing data but is able to attract specialists who can. In this scenario, there are disruptive technologies in the field so specialized and dynamic companies need to bring their fresh knowledge to the incubator. He can still choose between a few contractors with a performance-based maintenance contract or a bigger network of contractors (multiple individual service suppliers) with behaviour-based contracts, but needs to be aware that innovation is not always guaranteed and even can lead to higher uncertainty and new possible asset specific investments.

- 3) The Coordinator Scenario

The coordinator is capable of taking the main O&M activities in-house because the historical data of the performance is known, the data can be interpreted and there are no extra asset specific investments needed. Also, the coordinator is able to coordinate a wide range of contractors with the help of a behaviour-based contract and can guarantee potential innovation himself.

- 4) The Controller Scenario

The Controller is capable of taking the main O&M activities in-house, but he is also able to outsource with a performance-based maintenance contract because the performance of the turbines and O&M activities are known. The Controller has the knowledge about the impact of possible failures, the effect of corrective and preventive maintenance interventions and can control possible innovation dynamics with sub-contractors. The Controller can take full control over the post-warranty O&M activity.

So the performance-based maintenance contracts for the post-warranty O&M phase of offshore wind farms can be scoped by first identifying the proprietary nature of the owner, the knowability of the performance of the turbines and by examining the effect of innovations on the performance. This has to be identified for the turbine maintenance activities, offshore logistics and back-office activities. If the owner uses the decision-making flowchart that is presented in this research, he will be able to identify the sourcing scenario that is recommended or even needed in the post-warranty O&M phase. This contributes to a more efficient scoping of the current performance-based maintenance contract in the post warranty future, so that O&M costs can be minimized while keeping the performance high.

There are also other industries that could benefit from the scenarios and decision flowchart presented in this research. In general, the decision-making flowchart can help to find a new sourcing scenario for an owner that can choose between an in-house option, outsourcing with a traditional behaviour-based contract or with a performance-based contract. If heavy assets with long-term warranty periods and complex O&M activities are present in an industry that is affected by a dynamic level of innovation, the flowchart presented in this research could be interesting.

If these industries are able to split the O&M activities according to the six-stage model, they can use these activities as an input for the decision flowchart. For example, alternative industries could be multiple renewable energy industries, the Oil & Gas industry and the Rail & Road industry. Further research on the applicability in a specific industry is necessary before implementation of the flowchart.

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List of abbreviations

PBMC - Performance-based maintenance contract
LCoE - Levelized cost of energy
OWEC - Offshore wind energy converter
RET - Renewable energy technology
O&M - Operation and maintenance
CMS - Condition measurement system
OEM - Original equipment manufacturer

1. Introduction

1.1 Context

Since earliest times, man has admired the power of the wind. Throughout the 20th century, small wind plants and larger utility scale wind farms were developed and connected to electricity grids (Wind Energy Foundation, 2016). Wind turbine technology has developed rapidly in recent years, and now contributes significantly to our electricity supply.

The first offshore wind turbine was installed in 1991 in Denmark (Munksgaard & Morthorst, 2008). The advantage of offshore wind is that it achieves significantly more full-load hours than wind energy at land-based sites. Offshore wind farms also generally face less public opposition and less competition for space compared with development on land. These advantages result in large-scale projects and a promising future development (International Energy Agency, 2014). Offshore wind is a rapidly developing sector but the risks and costs are significantly high in comparison with energy from conventional sources (Tack et al., 2016). One way to lower the Levelized cost of Electricity (LCOE) is through technological innovation, which helps to harness more wind, more efficiently and at even lower costs. However, this also results in a constantly changing environment that affects wind farm owners (Pelosi, 2016).

Another way is to lower O&M costs of offshore wind turbines, which contribute substantially to the total LCOE of wind energy (Milborrow, 2010). With less than 30 years of experience, wind energy is a young market where standardized technical and commercial practices have not yet emerged. Thus, there are many paths offshore wind O&M can take (GL Garrad Hassan, 2013).

Wind farm owners are facing challenging decisions about their wind turbine O&M strategy after the first warranty period has ended. At the same time, new turbine suppliers and O&M service providers are entering the dynamic market, resulting into different sourcing options and possible reward systems (Kraemer, 2017). After the warranty period with the turbine supplier, the windfarm owner needs to find the best sourcing strategy that will result in the most favourable LCoE while keeping room for innovation of the aging wind turbines to produce as much energy as possible.

This thesis will present a decision making flowchart that wind farm owners can use to as a guideline to choose a suitable O&M sourcing strategy for their wind turbines in the post-warranty period. By doing so, I hope to contribute to a lower LCOE of offshore wind energy and provide a way to enable technological innovation within long-term projects.

1.2 Problem definition

While O&M costs of wind farms are decreasing relatively slowly, the market is increasing in size.

Over the next decades, offshore wind O&M is expected to become a significant industrial sector because of an increasing wind turbine capacity, wind farm size and the movement to further offshore distances. These trends are reflecting a period of continuous development in turbine technology and condition measurement systems to increase energy yields at sea (EWEA, 2016). As more and more offshore wind turbines are commissioned and the operational offshore wind industry continues to grow, the technical and commercial challenges of operating these complex projects are starting to receive attention. Nowadays, wind farm owners are taking a range of different approaches to contracting the O&M phase. Choices have to be made about the allocation of risk and responsibilities of the different activities (GL Garrad Hassan, 2013).

Developing the most appropriate O&M sourcing strategy becomes critical for wind farm owners when they want to secure an optimal performance of the total wind farm.

The main actors that are involved in the O&M phase of offshore windfarms, are the suppliers of the wind turbines, the owners of the windfarm projects, a variety of individual service providers (ISP's) and the owner of the electricity transmission connection (GL Garrad Hassan, 2013).

Normal procedure in the offshore wind energy sector is that the developer purchases wind turbines from a manufacturer. The contract usually includes a full O&M service agreement that guarantees the level of performance for a certain period (5-10 years). Many of these projects are just coming out of warranty between now and next ten years. As these warranties expire, owners face critical decisions about how to handle the post-warranty future, and the manufacturers and service providers face decisions about how best to align their interests with owners (Martin et al, 2008).

After the warranty period the owner has multiple currently available post-warranty sourcing options for offshore wind energy O&M.

- Renewal of the contract with the incumbent original equipment manufacturer (OEM): full O&M outsourcing agreement, ideally with a certain guarantee over performance (Performance-based maintenance contract, PBMC).
- Enter into a new contract with one or several service providers for different activities while keeping a close eye on these subcontractors.
- Take O&M in-house: Completely internal O&M including its own team to conduct all maintenance activities.
- A hybrid model: in which the owner performs certain tasks while subcontracting others to third parties (Kraemer, 2017).

This decision making process after the warranty period of the wind farm can lead to a lot of stress within the teams managing the contracts, both from the owner and the contractor perspective of offshore wind projects. Collaboration between owner and the OEM providing service has always been an issue during the warranty period, specifically with sharing of information and knowledge (Davidson, 2015). Yet OEM service providers, with greater access to data on the turbines, can also alert to problems sooner because of their in-depth technical knowledge (Davidson, 2015). Instead of working with the OEM, new and broader ideas by individual service suppliers in this field can stimulate innovation, which can lead to an increased energy output. Einstein explained this phenomenon in the following sentence: 'No problem can be solved by the same kind of thinking that created it'. On the other hand, there is a certain amount of wisdom in sticking with the manufacturer because you can build on understanding of issues in the past (Kraemer, 2017).

Concerning the maintenance performance, the parties run into an uncertain relationship of dependence (Hypko et al., 2010). Fundamentals that have a big influence on this decision in the wind farm O&M phase are availability, risks allocation (predictive & preventive), accessibility and costs, which lead to the overall LCoE. The expectations are high and many risks and responsibilities have to be transferred or taken in-house.

Eventually the scope of the final contracted activities has to be defined clearly. When the scope is not properly defined or bounded, this can increase the risk to one or more of the parties, which, in turn, can affect the total LCoE (Australian government). In figure 1, the currently available post-warranty sourcing options in the Netherlands are presented. In this thesis the possible sourcing strategies will be thoroughly examined which can lead to different options than is currently available.

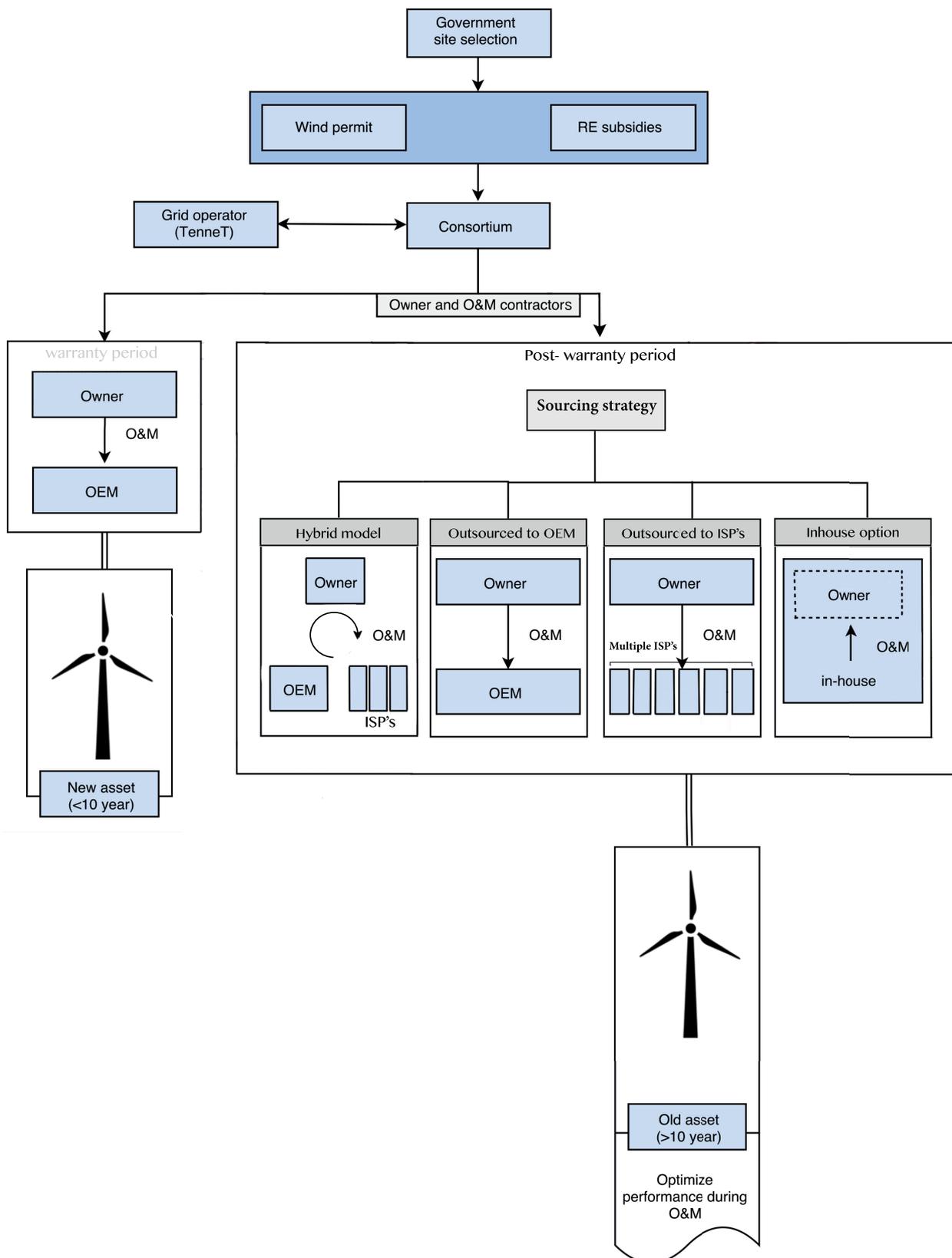


Figure (1), Currently available post-warranty sourcing options for offshore wind energy O&M. Based on Dvorak, P. (2013), Wind Energy Update (2013) & Kraemer, S. (2012).

During the warranty period, traditional performance-based contracts based on availability guarantees are offered by the turbine manufacturer (Kraemer, 2017 & Schontag, 1996). So during this period the contract is based on a guarantee of the total time turbines would be unavailable due to predictive and corrective maintenance activities. But this way of contracting where the owner has a passive role can have a negative influence on aligning the interests of the wind farm owners (Kraemer, 2017).

So, the main problem of this research entails:

Wind farm owners face difficult decisions when finding the right O&M contract for their specific offshore wind farm after the warranty period has ended (Wind energy update, 2013). Because of a lack of experience in this new operation and maintenance phase, these decision-making processes are not yet structured. This is a current problem for wind farm owners who were pioneers in the early 21st century by creating the first big offshore wind farms but now have to compete with the newest renewable energy technologies in the wind industry (Dvorak, 2013).

The post warranty sourcing strategy of offshore windfarms needs to guarantee innovation in new technologies and a reduction of the levelized cost of energy (LCoE) to eventually create a stronger position in the energy market.

When the scope of the performance contract is not properly defined or bounded, this can increase the risk to one or more of the parties, which, in turn, can affect the total LCoE (Australian government). To stimulate innovation and increase the energy output, some O&M activities may be better off outside the scope of the performance contract and need a different sourcing option.

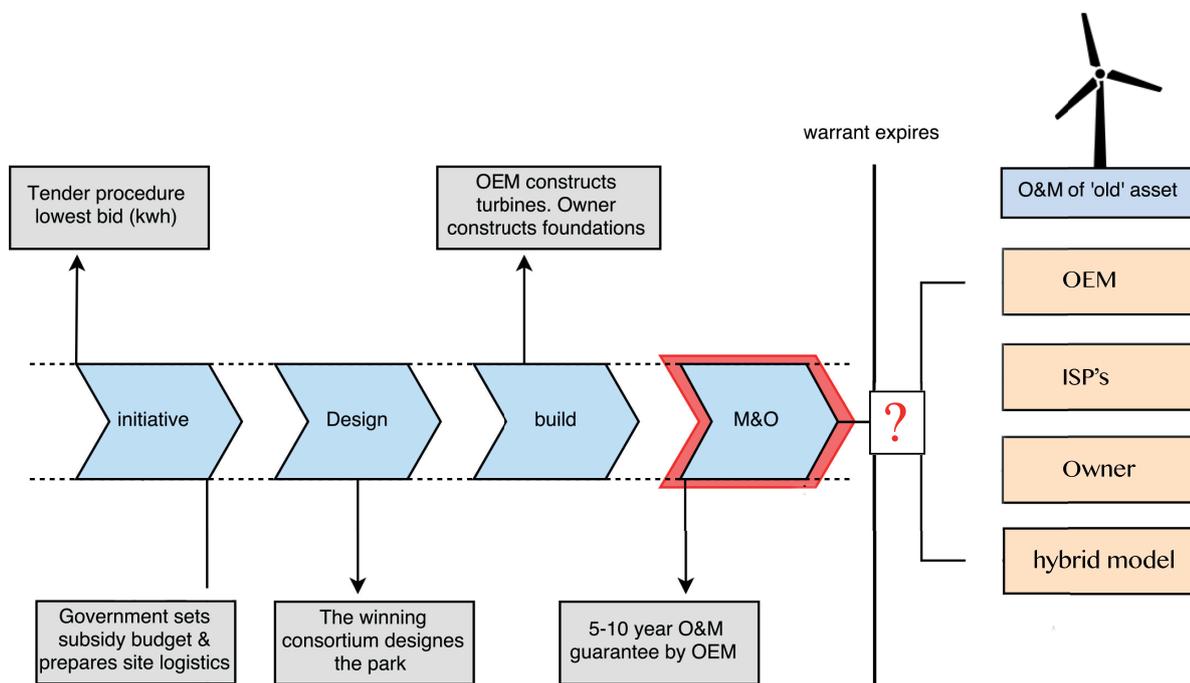


Figure (2), The end of the warranty period. Based on Dvorak, P. (2013) & Kraemer, S. (2012).

In figure 2 presented above, a short overview is given of the four main phases in the lifetime of a wind turbine. The problem leading to this research arises where the question mark symbol is sketched. The questionmarks symbolizes the absence of a structure that leads to a specific O&M sourcing option. In this research the aim is to fill this gap.

1.3 Research objectives & the research question

1.3.1 Objectives

The aim of this research is to compose a decision-making framework that can be used when finding a sourcing strategy for the maintenance of offshore wind farms. With this decision-making framework, wind farm owners will be able to reduce their O&M costs and stimulate efficiency and innovation.

The earlier mentioned problem statement identified the current absence of a structure that can be used when searching for a sourcing strategy in the post warranty future. The framework needs to consist of the main driving O&M activities in the offshore wind, sourcing decision variables, and sourcing scenarios with the final consequences of the decisions made. This decision-making framework needs to function as a guideline for future sourcing decisions from the owner's perspective.

The objectives for this research will be: (1) To identify and structure the activities that are part of the O&M phase and the performance drivers of the offshore wind turbines. Next, (2) to identify the relevant contract variables in the decision-making process for a sourcing strategy from a theoretical perspective; (3) To analyse possible sourcing scenario decisions and structure the influencing variables and activities in a framework that can be used when defining the scope of the performance contract. Finally (4), provide scenarios and recommendations to wind farm owners on how to scope performance-based maintenance contracts in the post-warranty period of offshore wind farms.

1.3.2 Research question & subquestions

In figure 3 presented below, the research fields leading to the research question are shown.

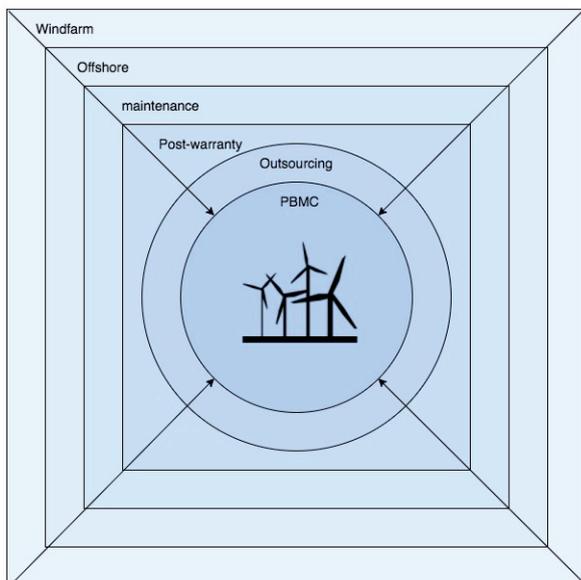


Figure (3). Research field scoping. Own figure

- > Wind farms
- > Offshore wind farms
- > Maintenance of offshore wind farms
- > Post-warranty maintenance of offshore wind farms
- > Outsourcing post-warranty maintenance of offshore wind farms
- > Scoping PBMC's when outsourcing post-warranty maintenance for offshore wind farms

The main research question is formulated below:

‘How to scope performance-based maintenance contracts for the post-warranty O&M phase of offshore wind farms?’

The stated research question above leads to the following main subject of this research:

‘Sourcing post-warranty O&M in the offshore wind industry: a decision-making framework’

In order to answer the research question, this thesis will firstly provide some basic knowledge on the offshore wind industry and performance contracting followed by several subquestions that will eventually answer the main question. The subquestions are listed below.

- (1) What are the main offshore wind farm O&M activities?
 - > What are their cost-drivers?
 - > What is their influence on the performance of the wind farm?
- (2) Which contract theory variables are relevant in the decision-making process for a new sourcing strategy for offshore wind farm O&M?
- (3) What are the decision-making options within a performance-based contract for post-warranty O&M of offshore wind farms?
- (4) How do the sourcing strategy options influence the decision-making variables and what are the consequences?

The first subquestion will explore the different activities that belong to the maintenance and operation phase of the offshore wind farms. For the performance contract it is important to know what the effect of the various activities is on the performance output. The operation and maintenance activities do not only drive the performance but also drive the costs. This first research question also discusses the impact of the various activities on the LCoE.

For constructing a decision-making framework it is essential to have decision-making variables that have an influence on the decision-making process. Within subquestion 2, these variables are derived from literature on contract theories.

Combining the O&M activities with the decision-making variables will lead to the solution space for the main question.

During the warranty period the total O&M activities are outsourced to the turbine supplier with the availability as a performance guarantee. The definition of ‘scoping a performance contract’ is determining the extent of activities that are involved in the performance contract. As shown in figure 4, the post-warranty O&M phase could have a different scope of the contract. The decision-making options that will define this scope are discussed within the third sub-question.

The last sub-question consists of the effects of the sourcing strategy options on the earlier defined decision making variables. This needs to guarantee the consistency of the final framework.

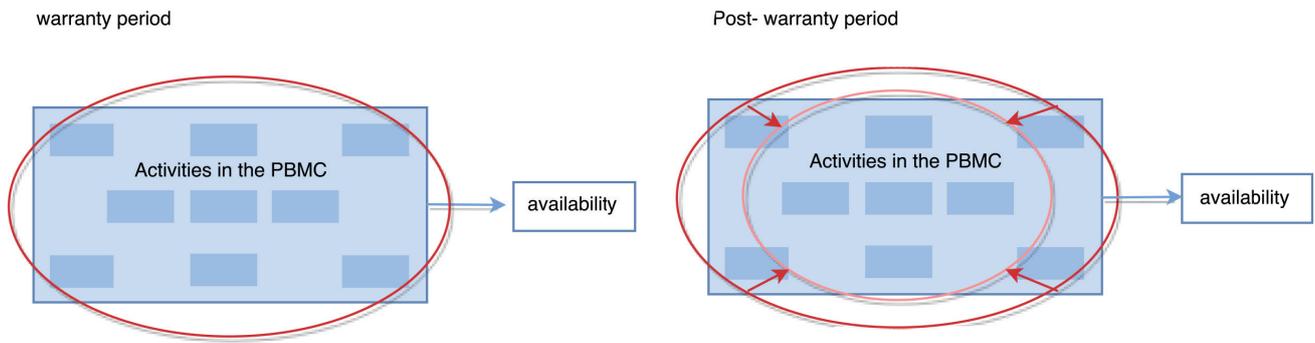


Figure (4). scoping the performance based contract

These sub-questions together will provide all the input needed for the decision-making framework. The framework drafted from the knowledge gained in the literature study, will be tested and adapted during the empirical part of the research to find out if the decision-making model works for the wind farm owners. Next, the final framework will be validated and conclusions will be drawn.

The total research outline is presented in paragraph 2.1.

1.5 Clarification of concepts

Before explaining the research scope in the next paragraph, it is important to clarify the concepts that are used throughout the research.

(out)sourcing

When an organization is in the process of finding suppliers of goods or services, it can choose to outsource activities to these suppliers and services or do it themselves. The basic reason for outsourcing is that it provides a cheaper and/or better service than if then doing it yourself (Hastings, 2015, ch.16).

The definition of outsourcing according to the ISO55000 is: 'To make an arrangement where an external organization performs part of an organization's function or process'.

When the organization chooses to outsource any activities, it shall ensure control over such activities with the following requirements (ISO55000):

- The organization shall determine the process and activities that are to be outsourced.
- It shall determine the process and scope for the sharing of knowledge and information
- It shall determine the responsibilities and authorities within the organization for managing the outsourced process and activities.

Outsourcing of maintenance activities from utilities and large-scale enterprises has occurred on a substantial scale in recent years. It enables an organization to be equipped, trained, skilled and experienced in a chosen range of tasks and to outsource activities that are not included in its core activities (Hastings, 2015, ch.16).

Post-Warranty

Typically, wind turbines are under warranty for the first 5 years and sometimes even 10 /15 years of their lives (GL Garrad Hassan, 2013). During this warranty time, original equipment manufacturers (OEM's) provide full O&M services.

After this warranty time, the wind farm owner may operate the wind farm itself, contract to a individual service provider (ISP) or develop an intermediate arrangement (GL Garrad Hassan, 2013). In this research the focus is only on contracts for post-warranty O&M services. Therefore, we do not discuss decisions required in initial phases of project development, such as decisions in the design or construction phase. Rather, we consider decisions regarding O&M actions executed after the wind park starts operation and reaches the end of the warranty period (Sanz-Bobi, 2014. P.154-159).

Offshore windfarms

Before continuing on the potential of offshore wind farms and the contribution of the certain performance contracts in the O&M phase, we first focus on the definition of these 'offshore wind farms'.

Wind power can be defined as:

'Wind power refers to the extraction of kinetic energy from the wind and conversion of it into a useful type of energy: thermal, mechanical or electrical' (Hexa research, 2017).

According to the energy data platform Open Energy Information, an offshore wind farm can be defined as:

'Wind turbine installations built near-shore or further offshore on coastlines for commercial electricity generation.'

The International Energy Agency defines offshore wind the following way:

'Offshore wind energy refers to the energy generated by wind turbine deployed in the sea. Depending on the depth of the sea, this area can be several tens of kilometres off the shoreline'

With the three definitions stated above, the following definition of offshore windfarms used in this research is composed:

'Offshore wind farms are wind turbine installations built near-shore or further offshore that extract kinetic energy from the wind and covert it into useful energy for commercial electricity generation'

The definition of PBMC including background literature will be further examined in chapter 3.1.2

1.6 Research scope

In order to conduct this research it is important to have a clear vision on the scope in which the research will be done. As this thesis is written for the master Construction Management and Engineering with a focus on asset management and performance contracting, the research will address the maintenance and operations of one of the newest heavy assets, the offshore windturbine. In the following sub-paragraphs the scope of the research is further defined.

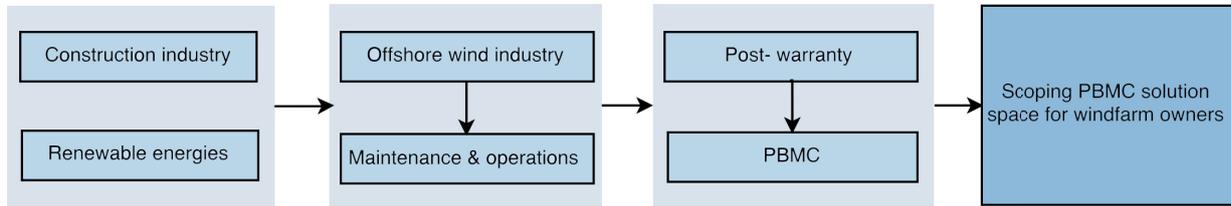


Figure (5). Research scope

Industry scope

In figure 6 the different industries and their components are sketched. It gives a representation of the research boundaries within the construction industry. As shown in the green box, the main scope is the offshore industry. The red boxes are outside the scope of this research.

The illustration below shows that the Oil & Gas industry and the Rail & Road industry are neither red, nor green. The Oil & Gas industry is closely related to the Wind energy industry because the companies that are active in the wind industry are often traditional energy companies with a lot of expertise in offshore activities. Maintenance and operations expertise from this offshore conventional energy industry could be relevant when researching the risks and difficulties in the offshore sector.

Of course, the PBMC's are not only used in the wind industry. Other civil engineering industries, in particular the Rail & Road industry, are also innovating in the outcome-based contract forms (Schoemaker, 2011).

Theory on the PBMC's experience in this industry will be used as a contribution to the main scope to highlight differences between the well-known civil industries and the new, less mature, offshore wind energy industry.

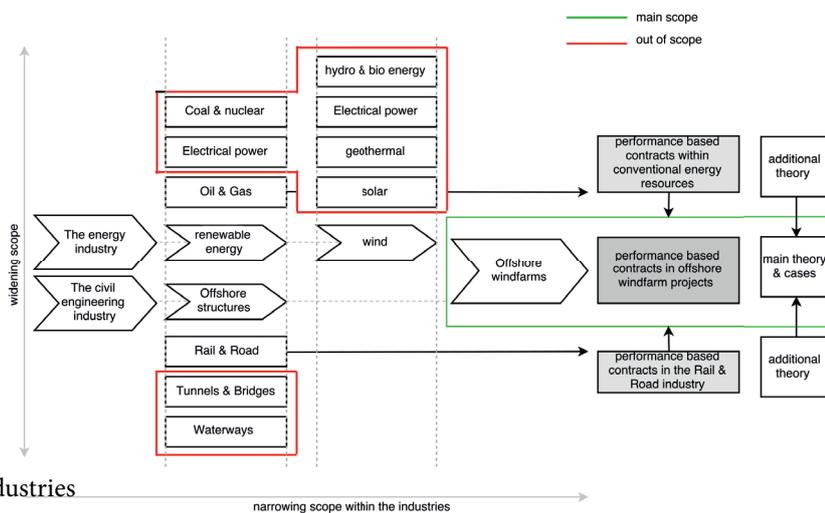


Figure (6). Scope of industries

Supply chain scope

The research is focused on the O&M phase of post-warranty wind turbines from the perspective of the owner of a windfarm. The warranty period and the earlier phases, being the initiative-, design- and build phase are not included in this research. A more detailed definition of the Operation and maintenance definitions and activities are further examined in chapter 3.

Theoretical scope

In this research the measurable variables are gathered by using contract theory.

Contract theory is the study of the way individuals and businesses construct and develop legal agreements. It researches how parties make decisions to create a contract with particular terms in case uncertain conditions happen (Rossignoli & Ricciardi, 2015).

There are a few main theories in this field of study. In this research the focus is going to be on Transaction cost economics (TcE) and the Principle-Agent theory. With these two theories the focus of the variables is divided in the following two categories (Rossignoli & Ricciardi, 2015):

- Transactions (market vs. organization)
- Contracts (behaviour vs. outcome)

These two theories see inter organizational relationships as coordination and control issues. Further research on these two theories is done in chapter 4.

Physical asset scope

The asset specific focus in this research is on the maintenance of the wind turbines of a windfarm excluding the foundation. The wind turbine is the actual energy converters, which is the key element of a wind farm. It consists of the most high-tech mechanical and electrical subcomponents that have to operate in a rough offshore environment. In contrast to the offshore foundations, the risks and uncertainties of the turbines are higher, resulting in a direct impact on the availability and energy output (Schontag, 1996).

1.7 The research outline

This thesis report will start with the explanation of the research methodology in chapter 2. Chapter 3 will display the literature review regarding the PBMC's in offshore wind are discussed and were the first subquestion will be answered. Chapter 4 is dedicated to the theoretical contract framework that will help to create a clear perspective of the theoretical solution space before starting with the cases. Here the Transaction cost theory and Agency theory are discussed. In chapter 5 the first draft version of the decision-making framework will be composed and this will be used as the input for the cases.

After the literature review and the draft framework, the two cases will be reviewed in chapter 6, to get a more complete picture combining the literature with practice. In chapter 7 there will be a reflection on the cases and the answers on the last two subquestions are given. In this chapter the final model will also be validated by experts in the field and the added value and limitations will be further examined. Here the results of the literature review including interviews and the cases will come together in a final decision-making framework that wind farm owners can use when finding a new sourcing strategy for the post warranty O&M phase of their wind farm. Next, in chapter 8 the conclusion will answer the main research question. After defining the conclusions, recommendations for further research will be given in chapter 9, followed by the discussion the discussion in chapter 10.

A schematized research outline that clarifies the structure of this thesis is presented in the research methodology.

2. Research methodology

2.1 Nature of research

To answer the research question and to achieve the research objective, a research strategy is used. In figure 7 an overview of the research design is shown in a schematized research outline. The research starts with a literature study. Next, a draft version of the decision framework will be conducted before starting the cases so the cases can be used to further optimize the decision-making framework and solution space. The conclusion of the cases and results of the literature study are combined to answer the main research question. Finally, a validation step forms the conclusion and recommendations. The literature review, case studies, framework and validation step are further elaborated in this chapter.

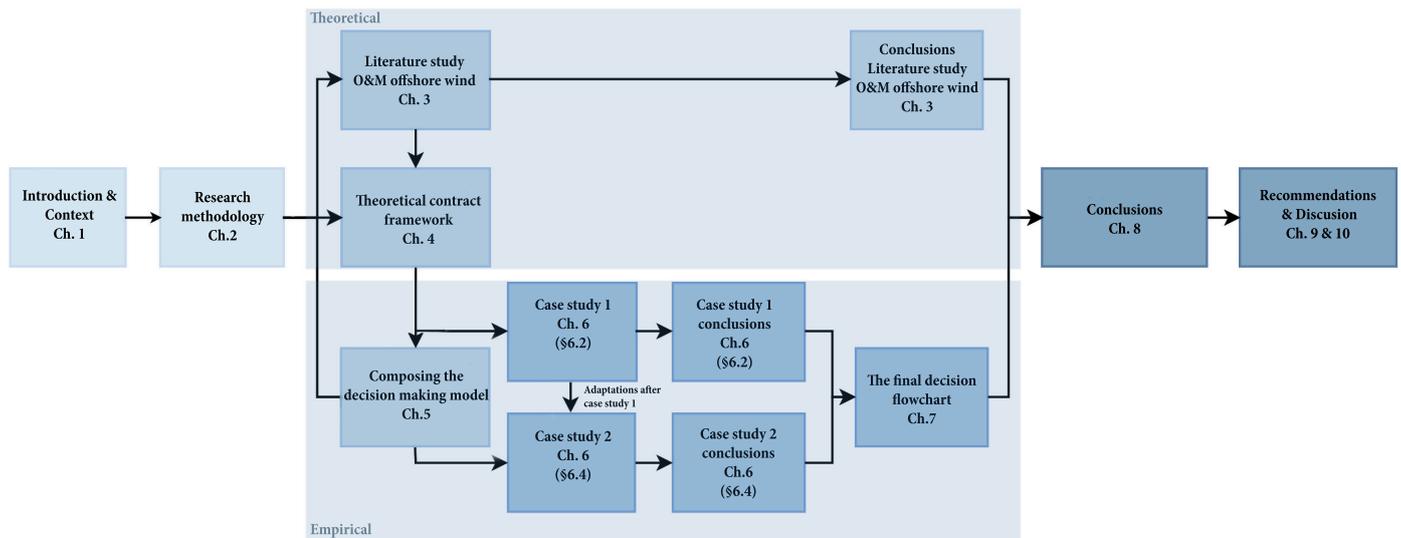


Figure (7). Research outline

According to Verschuren & Doorewaard (2010), this research can be described as a qualitative empirical research because a thorough literature research is done and observations are made to answer the final research question. Given the timeframe for this master thesis project and the type of information needed from cases and interviews, a qualitative research was the most convenient option.

The nature of the research becomes comparable with a design-oriented research. This research method consists of a plan to obtain certain structural solutions. The structural solutions will be combined in the decision-making framework. In this case the research perspective does not only stem mainly from a theoretical analysis but also from the interviews and case studies in which the researcher determines on empirical grounds the design specifications (Verschuren & Doorewaard, 2010). Every case will lead to new adjustments of the decision-making framework to create a constant process of improvement of the design. At the end, a solid framework based on literature and tested in real life cases, can be presented.

General conclusions can be drawn when comparing the specific scenario options in the offshore wind energy market with similar markets.

2.2 Linking research strategy with subquestions

Several sources of information can be used when constructing a research strategy. Questions that arise we have to ask ourselves is what should be observed during the preliminary research study, which experts should be consulted and which documents and literature should be studied. In figure 8, presented on the next page, the main components that have to be observed are listed. In the middle the key components derived as output of the subquestions are stated. Also the subcomponents and their sources are mentioned.

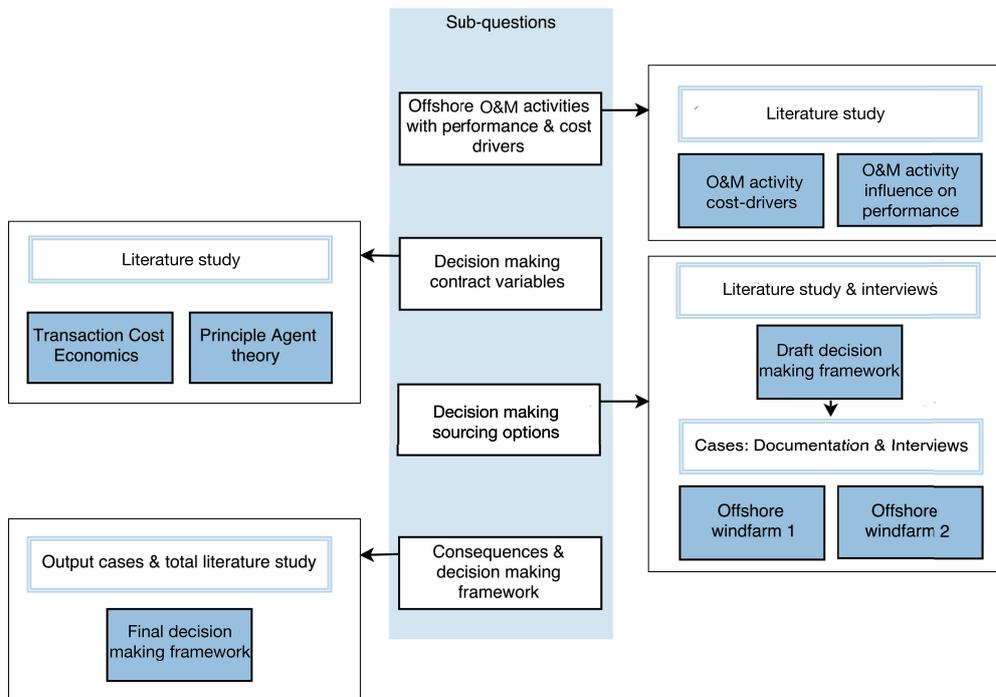


Figure (8). Research outline

2.3 Literature review

The first two subquestions are answered in the literature review and provide the basis for the cases studies. The goal of a literature review is to create a clear overview of what past research has showed about the area of the research topic (Saunders et al., 2009). The main focus in the literature review part is on the cost-drivers and performance drivers within the O&M phase of offshore wind farms. Also, the characteristics of a performance-based maintenance contract are explained.

Next, with the transaction cost theory and agency theory, the contract theory variables that are relevant in the decision-making process will be defined. These contract theories are used to create the first draft framework that is used to tackle the cases.

The results of the literature review are the input for the case studies. The literature is the basis for this research and the findings are gathered in a draft version of the decision-making framework. Next, this draft version, which includes possible sourcing strategies is applied during the cases including empirical data. The case studies can also show new insights that could be added to the existing draft version so that it becomes a solid framework that can be used in practice. This part is the inductive part of this research because it searches for patterns from observation and the development of certain explanations.

2.4 Composing the framework

The draft framework is composed by combining the Offshore O&M background literature and the PBMC decision-making variables. The literature will be used to compose a first version of the decision-making framework. The composition of the framework part is comparable with a design-oriented research.

This first framework structure answers the third sub-question regarding the sourcing options .

This will be used in the first case, after which it may be adjusted or improved with the experiences from the first case. The literature background part will be complemented with interviews regarding experts in the offshore wind maintenance field, offshore logistic experts, experts in the back-office operations activities and people that are experienced in performance-based contracting of heavy assets.

During the second case the adjusted framework will be used again to run the real life decisions through the composed framework. New insights and a comparison with the first case lead to a validation of the framework. Finally, the framework can be used when owners want to scope the performance-based maintenance contracts for their offshore wind turbines.

2.5 Case studies

After the literature study and the interviews, the next step of this research consists of two case studies to collect data from practice that can be run through the framework leading to the answers on the last subquestion regarding the consequences of the decisions made on the decision-making variables. As the main objective of this part of the research is to run the observations of the cases through the framework, it is chosen that the wind farm cases meet the following criteria (figure 9).

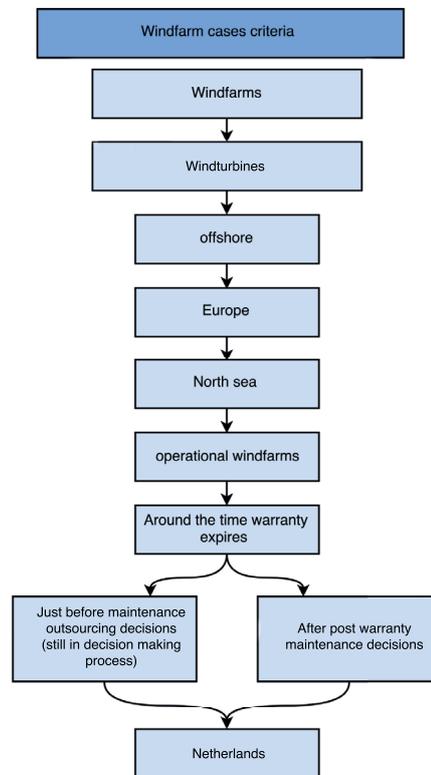


Figure (9). Scope of the cases. based on WindEurope (2017)

As already mentioned, this research is only focused on the sourcing options for wind turbines, which means that the foundation, grid connection and other offshore sub-systems are out of scope.

The cases have to be located in the North sea so the environmental parameter will stay consistent. For the research it is important that there are not only a post-warranty case but also an ante-warranty case to get more involved in the decision-making process in the current practice. To get an easier access to information & data about the cases and to narrow the scope, there is chosen to focus on offshore wind farm projects in the Netherlands. Next to the scoping criteria, some technical and asset specific requirements are set to create constant variables in the research that make comparisons between the cases possible.

- Operational before 2015: This means that the project has at least 2 years of O&M experience.
- The turbines of the project cases have the same manufacturer. The turbine types differ but the manufacturer is the same so that the original assets have a constant technical factor.
- The wind farm is medium sized, between 30 -100 turbines and 10-30km², and is able to deliver 100MW.

Three Dutch main operational wind farms meet the requirements stated above. Due to the fact that there are limited other windfarm options in the Netherlands, the choice for wind farms suitable for this research becomes obvious.

Unfortunately, a difficulty with finding a sufficient project case is the willingness of the client or contracting party to share the contract information and additional decision processes that are used to come up with a new post- warranty sourcing strategy. As this information is often confidential and generally not open to the public, this research partly depends on the willingness of the involved party to provide information. The two cases that will be sufficient for this research are called Wind farm Case 1 and Wind farm Case 2 to keep the information of the companies confidential. The third wind farm is used in the validation part because it is not yet approaching a new sourcing decision after becoming operational in 2015.

The important general-, technical- and O&M information that make the cases suitable are listed in table 1.

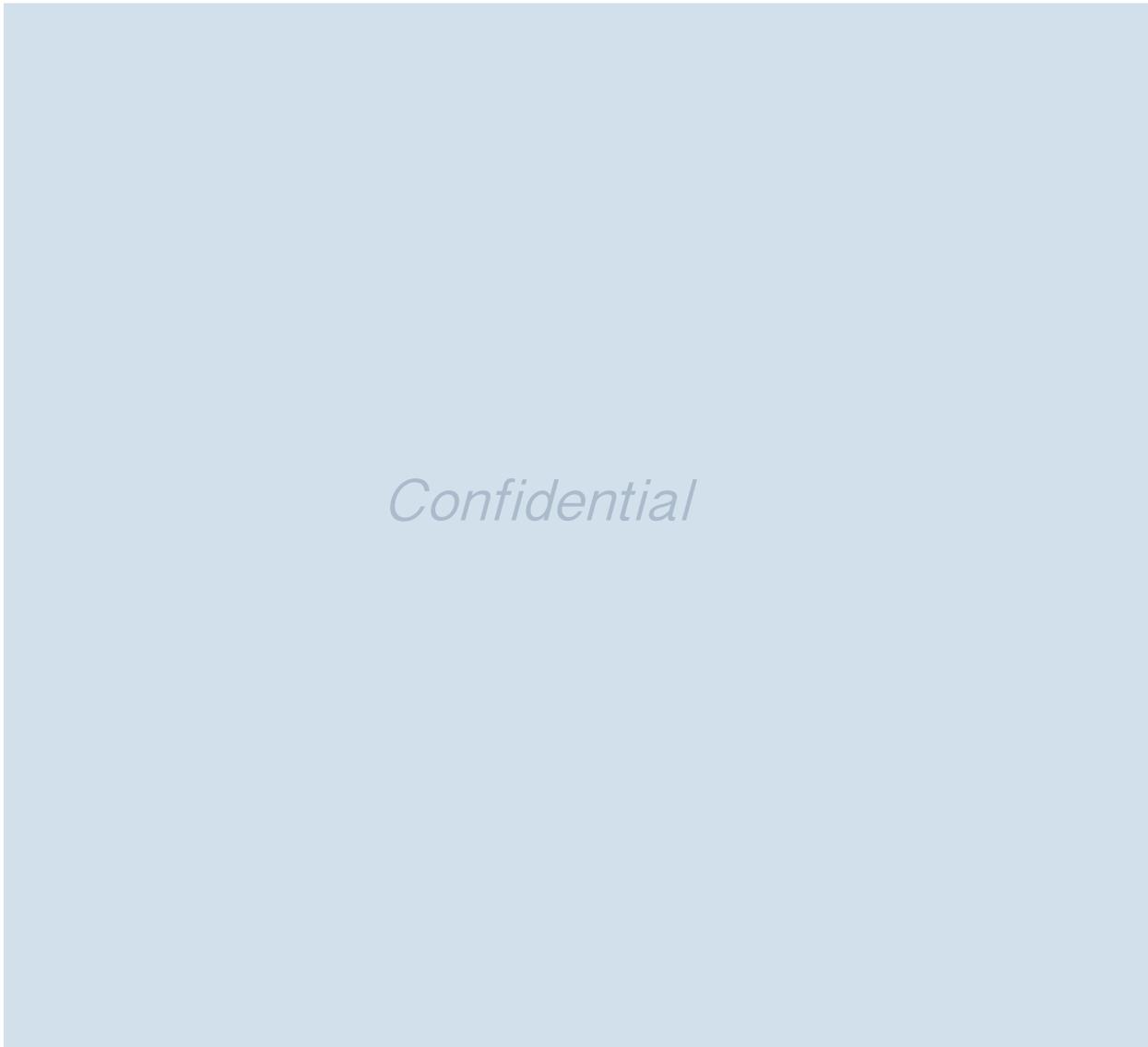


Table (1). Information on the cases

Based on 1.&2; 4cOffshore, 2017; Tissskink, 2014; Het Financieel Dagblad, 2016; C-Ventus, 2016; Deutsche Windtechnik AG, 2107; Delnooz, 2011; Meewind, 2012; Belwind offshore energy, 2017; Weston, 2014; Fonds Zweewind, 2017.

Within these two projects the aim is to answer the last research question and to eventually validate the decision making framework that wind farm owners can use when they are entering post-warranty sourcing decisions.

2.5.1 Document analysis

To collect data on the sourcing decision-making processes for wind farm owners with wind turbines in the North Sea, the different wind farms from table 1 were reviewed. A part of this review was going through sourcing strategy documents (KPMG) and project specific documents from the project owner.

Next to the project specific documents, relevant governmental information and news articles regarding the different projects were taken into account. Also a lot of asset specific information from both projects is publicly available. Due to the confidentiality of a lot of contracting documents, some of the information could not be analyzed and published.

This specific contract information was discussed in the interviews where owners were willing to give information on their decision-making processes when choosing a sourcing strategy.

2.5.2 Interviews

Parallel to the literature study process of the documents, semi-structured interviews were conducted to collect more information on the current situation in the wind farm industry. The parties that were interviewed are wind farm owners, the turbine manufacturer, asset management experts and experts in the offshore logistic field.

The interviews were a means to increase insight in the following aspects and themes:

Interviewees	Topics	Expertise
(I-A) Windfarm owner 1	PBMC, data management, CMS, OPEX/production, innovation	Wind farm 1 O&M strategies
(I-B) Windfarm owner 2	PBMC, data management, CMS, critical components, innovation	Wind farm 2 O&M strategies
(I-C) Original Equipment Manufacturer	Data management, CMS, future prospects OEM	OEM multiple offshore windfarms in the Northsea
(I-D) Offshore contractor	PBMC, data management, CMS, offshore logistic strategies	Offshore logistics & vessel transport
(I-E) Public asset owner	Prestatiecontracten, data systems, information assymetry	Prestatiecontracten
(I-F) Asset management advisor	PBMC, data management, CMS	PBMC & Asset management
(I-G) corporate culture & innovation theorist	Internal control, data management, innovation	Organizational change management

Table (2). Interviews

The interviews were semi-structured because of the amount of uncertainties and dynamics in this current field of studies. These semi-structured interviews fit the exploratory in-depth research (Saunders et al., 2009). Prior to the interviews, the interviewees received a short introduction about the topic, the goal of the interview and the kind of questions they could expect.

After reviewing specific documents or during the interview sessions, often other topics and interesting additional information were discussed. The interviews were either recorded and transcribed or handwritten notes and graphics were taken (see Appendix E).

These different approaches were depended on the situation of the interviews and the confidentiality of the contractual topics that were discussed. The detailed list with interviewees can be found in appendix E.

The interviews were taken on either the owner site or the (sub-) contractor site.

2.6 Validation

For the validation of the findings of the research, different expert meetings were planned. Also the experts of the two cases will comment on the results of the literature review as well as the construction of the qualitative decision-making framework. They can critically review the results of the cases and compare them with their own observations from past experiences.

This first framework structure answers the third sub-question regarding the possible decision-making options within a performance-based contract for post-warranty maintenance.

This will be used in the first case, after which it may be adjusted or improved with the experiences from the first case. During the second case the framework will be used again to run the real life decisions through the composed framework. New insights and a comparison with the first case lead to validation steps during the analysis. Also the OEM of both cases will be asked to validate the framework, which will give the reader more insight in the perspective of the OEM. Lastly, one windfarm owner is asked to compare the results with the developments at a new generation wind farm that opened two years ago.

The results of this validation can be viewed in paragraph 7.4.

3. Literature review on performance-based contracting in the offshore wind industry

This chapter will provide a theoretical background on performance-based contracting, the O&M activities within the offshore wind industry and the contract theories from which the decision-making variables are drawn.

The literature will help in trying to answer the following sub-questions of this research:

- What are the main offshore wind farm O&M activities?
 - > What are their cost-drivers
 - > What is their influence on the performance of the wind farm
- Which contract theory variables are relevant in the decision-making process for a new sourcing strategy for offshore wind farm O&M?

3.1 An introduction in Performance-based contracting for O&M activities

To answer the main research question and its sub-questions, it is important to obtain more knowledge of the maintenance and operations phase in general and to define the definition of a performance contract that can be used to outsource the activities within the maintenance and operations phase.

3.1.1 Maintenance & Operations

The physical scope consists of operation and maintenance activities carried out within the total O&M phase. The function of the full O&M phase is eventually to provide support during the lifetime operation of the wind farm to ensure optimum output (GL Garrad Hassan, 2013).

Every operating system has a point in its lifetime that it shows malfunctions and failures. The objective of maintenance is to bring this system back towards a state of failure free operations.

The definition of *maintenance* is as follows:

‘Maintenance is the contribution of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, restore it to, a state in which it can perform the required function’ (CEN. 2001).

There are two different types of maintenance policies called ‘corrective maintenance’ and ‘preventive maintenance’.

Whereas preventive maintenance aims to reduce the probability of failures the corrective maintenance implies a maintenance action after the failure already occurred. Preventive maintenance can be further decomposed in scheduled preventive maintenance and condition-based maintenance. Condition-based maintenance is a maintenance strategy with a lot of new innovative techniques that can reduce future maintenance costs. Conditions can be measured on specific times leading to a discrete sample that can be used for stochastic calculations. It is also possible to choose for condition-based monitoring where sensors can lead to continuous data. Condition-based monitoring is done with Condition Monitoring Systems (CMS) that allow maintenance to be scheduled and can predict the impact of consequences with a defined certainty.

The above-mentioned maintenance strategies are organized in figure 10.

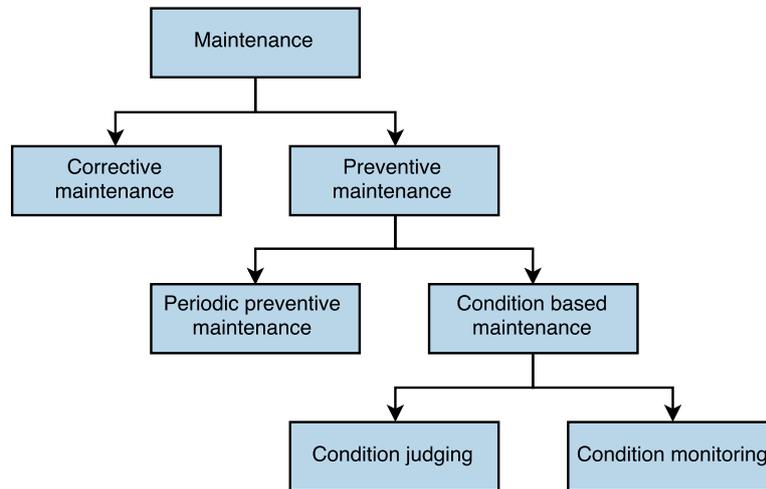


Figure (10). Maintenance decomposition based on Schontag (1996) & Hastings (2015)

So the maintenance activities are focused on providing routines observation, service and repairs, while the operating activities are based on monitoring and managing maintenance (GL Garrad Hassan, 2013).

The operation part of the O&M phase is based on monitoring and managing maintenance (GL Garrad Hassan, 2013). So the function of the operation activities is to monitor the performance of the asset, plan maintenance schedules and include management of the customer and supplier interaction.

These operating activities include costs such as information technology systems, operational documentation, equipment and facilities for operational personnel (Hastings, 2015, p.153).

These activities are also part of the scope of this research because the research will capture the whole O&M phase. Other operating activities that are not directly related to the maintenance of the wind turbines such as taxes, insurances and land rent are out of scope for this research.

3.1.2 Performance-based maintenance contracts

The O&M phase of an asset can be outsourced to a contractor with different kind of contract agreements. In this research the focus is on Performance-based maintenance contracts (PBMC). In this sub-paragraph the definition and additional information on these PBMC's are discussed.

The 'Performance-based' part of the PBMC definition is seen as the set of activities that is needed to keep the required function(s) available at the agreed level of service (Schoenmaker, 2017).

A performance-based maintenance contract is a contract in which (Schoenmaker, 2017):

- The principal:
 - Describes the desired situation using performance requirement
 - Shows restraint in prescribing activities
- The contractor has freedom in design and execution of the work
- There is a link between the delivered performance and payment
- The performance requirements have to be maintained over a period of time.

So according to the above literature it can be concluded PBMC's are output-based contracts. Here we define output as the result of a process (ISO 14001).

The performance requirements that have to be met are the output. If we look closer at the Performance-based maintenance contracts for wind farms we actually see that the delivered performance is not the total output but the total outcome. This means it is not only the result of the process that has to be defined in the contract but also the achievement that has to be obtained, is included in the contract. Here the outcome can be defined as the consequence of the output (ISO14001).

The performance-based maintenance for wind farms is often managed under energy performance contracting where terms are fixed regarding the energy delivery requirement and the availability of the wind turbines (Sandborn et al., 2016).

These performance contracts vary in their level of support and guarantee. The contracts appear to be designed to remove large amounts of perceived risk of offshore maintenance from the operator/owner at a fixed premium (Caroll et al., 2015). Some contracts focus more on the availability of the wind turbines while others are more based on the minimum energy output requirements.

For wind farms and in particular offshore wind farms, maintenance of the individual turbines cannot be done continuously. In this case the maintenance activities performed at a maintenance opportunity depends not only on the state of health of a particular turbine, but also on the state of health of other turbines. So we cannot only look at the output of one asset, the wind turbine, but have to look at the total outcome of the wind farm (Sandborn et al., 2016).

3.1.3 Six stage model

Now the definition of PBMC's and the application of these contracts in the offshore wind industry is known. In this sub-paragraph the O&M process steps are defined and structured by the introduction of the Six Stage Model. This model is used to clarify the process steps that are included in the PBMC.

Different maintenance strategy researchers such as David Sherwin (2000) emphasized the fact that O&M activities have a cyclic character. The main researches in the field identified three main cyclic processes (Schoenmaker, 2011; BSI, 2004a, 2004b)

1. Planning and execution of routine maintenance activities
2. Identifying, planning and executing maintenance within the existing performance requirements
3. Identifying, planning and execution of maintenance because of changing requirements

Schoenmaker (2011) summarized the maintenance process based on the earlier work of Dunn (1999) and Murthy & Kobbacy (2008) and added some new steps to create an easy to use model. Earlier researchers identified the model as the Six Stage Model but with the additional steps it does not only exist of six stages (figure 11). The blue lined square shows the part that has the aim to keep the asset available according to the agreed performance level and function. The activities within the blue box are included in the PBMC.

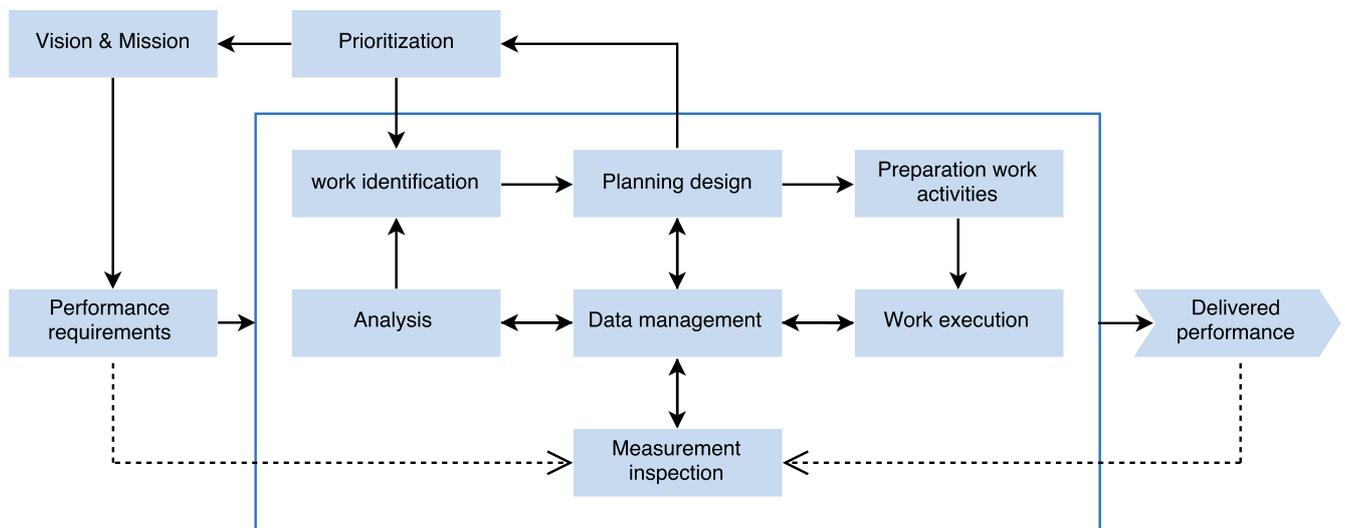


Figure (11). The Six Stage Model. Schoenmaker (2011), Dunn (1999) & Murthy & Kobbacy (2008)

The output is formed by the delivered performance that needs to meet the input, also known as performance requirements. This means that the model contains both the first and the second cyclic process. The third cyclic process is not presented in the scheme. If the performance requirements change due to customer (dis-)satisfaction, the input of figure 11 will change (Schoenmaker, 2011).

Process step	Explanation
Mission & Vision	Find an interpretation of the strategic corporate goals for the specific offshore wind energy project.
Performance requirements	Translate the strategy in specific, measurable, acceptable, realistic and time based goals (SMART) that describe the requirements of the asset and support processes
Measurement, inspection	Guarantee an accurate record of the condition and performance of the asset
Data management	Manage an accurate, up to date and complete inventory of the network with condition and performance data in a suitable format for direct usage.
Analysis	Determine the trends, failures and spreading of intervention levels that could be in conflict with the performance requirements based on data, available knowledge and documents.
Work identification	Determine the most efficient and effective interventions for the certain needs to meet the performance requirements.
Planning and design	Create a routine maintenance plan, an incidental management plan and a long-range maintenance plan. Also create interventions that can be offered to the work preparation and execution steps so it can be executed within the agreed time and costs.
Prioritization	Weigh the proposed interventions in agreement with the criteria, budget and performance requirements. If needed, change the performance requirements when it does not fit the budget.
Preparation work activities	Set up a scheme for execution of the planned maintenance activities according to the performance requirements.
Work execution	Execute the planned maintenance activities.

Table (3). The Six Stage Model process steps. Schoenmaker (2011), Dunn (1999) & Murthy & Kobbacy (2008)

In the blue box that is sketched in the figure 11, the most right-handed cycle (planning design, preparation work activities, work execution and data management) is the short time loop consisting of routine maintenance activities. The left-handed loop (work identification, analysis, planning design and data manager) is more focused on upgrading the standard wind farm maintenance activities (Schoenmaker, 2011).

Both loops are shown in figure 12. The measurement and inspection step creates a history and database of the condition and functioning of the turbine during its lifetime.

In the wind industry the discrete interval detection of the performance is rapidly shifting towards continuous condition-based monitoring. This shift is dependent on the constant usage of the assets, the failure rates and possible consequences. In the data management step the performance data is used for analysis and is rated against the performance requirements and intervention levels. The identified performance trends and needed interventions are input for the 'planning design' step. During this step a routine maintenance plan, an incidental management plan and a long-range maintenance plan are created. The output can be offered to the 'prioritization' and subsequent 'work preparation' steps so it can be executed within the agreed time and costs. This is leading to constant iterative steps of the prioritization of the work and a new planning (Schoenmaker, 2011 & Dunn, 1999). In traditional O&M contracts only these work preparation and execution steps are outsourced (figure 12).

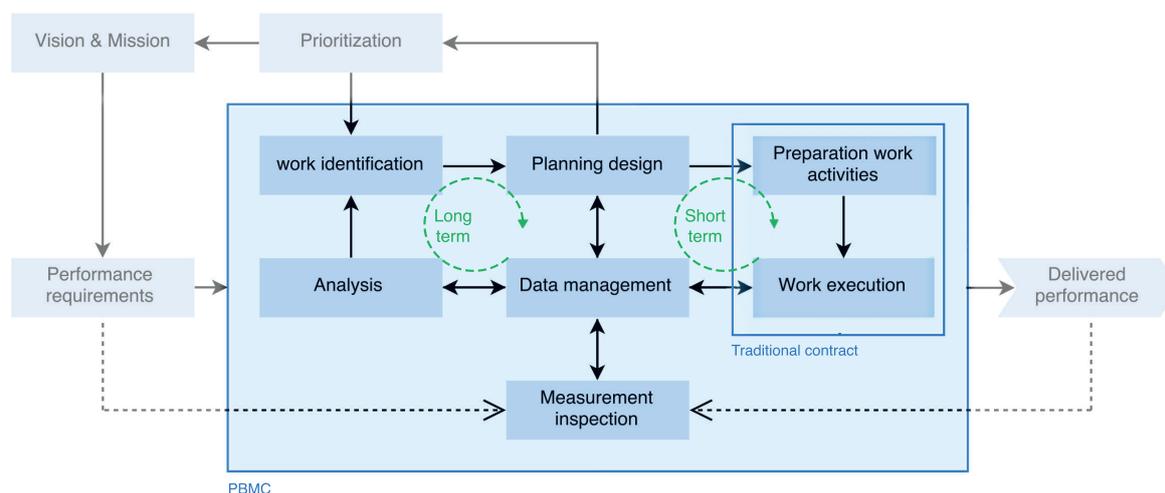


Figure (12). The Six Stage Model including time loops. Schoenmaker (2011), Dunn (1999) & Murthy & Kobbacy (2008)

3.2 O&M in offshore wind

In this paragraph the main offshore wind farm O&M activities are described and discussed to get a better understanding of the cost-drivers and performance indicators in the offshore wind industry.

3.2.1 An introduction in the offshore wind industry

The first wind farm projects are effected by innovation of rapidly emerging renewable energy technologies that help the industry harness more wind, more efficiently and at even lower costs, resulting in a constantly changing environment (Pelosi, 2016).

The advantage of offshore wind is that it achieves significantly more full-load hours than wind energy at land-based sites. Offshore wind farms also generally face less public opposition and less competition for space compared with development on land. These advantages result in large-scale projects and a promising future development (International Energy Agency, 2014). With a few large-scale wind farms already designed and constructed, the first offshore wind farm operation and maintenance (O&M) activities are executed.

The goal within the industry is to keep innovating in new technologies to achieve higher output and at the same time reduce the levelized cost of energy, leading to a smartly shaped energy transition.

The picture illustrated in figure 13 provides an overview of the key offshore wind operation and maintenance activities (GL Garrad Hassan, 2013). The red box presents the scope within the offshore wind O&M industry that is set for this research. The scope includes the turbine maintenance and the offshore logistics that are needed for the turbine maintenance. The foundation maintenance, onshore logistics, cable and grid connection and array cable maintenance are out of scope in this research.

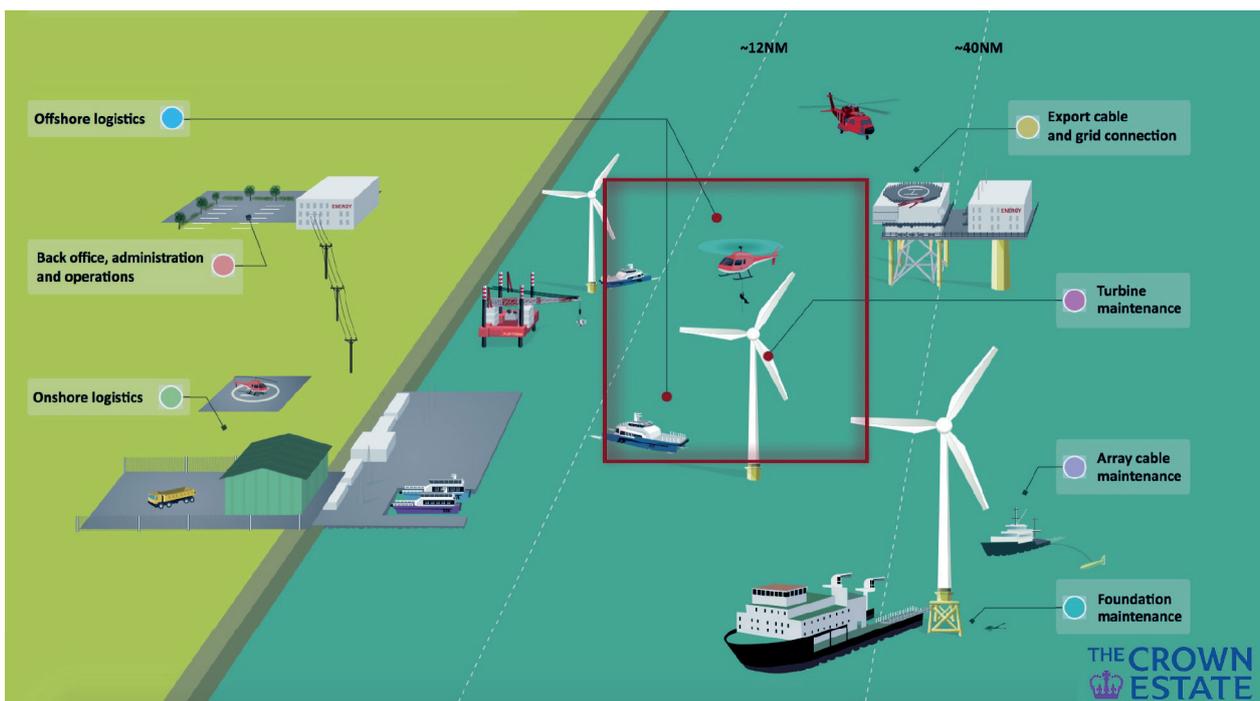


Figure (13). The offshore wind activities (GL Garrad Hassan, 2013)

The function of wind turbine maintenance and the offshore maintenance logistics is eventually to provide support during the lifetime operation of the wind farm to ensure optimum output (GL Garrad Hassan, 2013). These activities aim to optimize availability and capacity of a wind farm whilst keeping costs to an acceptable level.

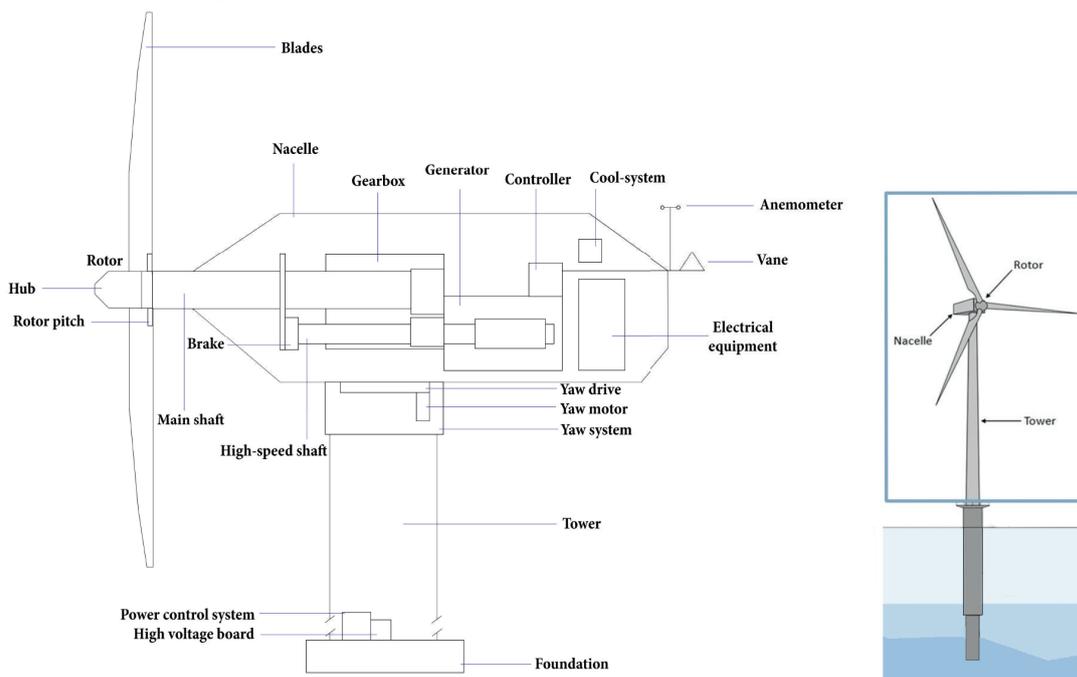
The O&M phase is normally the bulk of the total life cycle of an asset during which it provides the function for which it was designed (Davis, 2015). The function for which wind farms are designed is generating wind energy that can be transferred to the grid. During the operating and maintenance period the asset should be subject to appropriate monitoring, maintenance, refurbishment and potential upgrade to meet any change in the overall performance (Davis, 2015).

The general function of the operation activities is to monitor the performance and to plan maintenance schedules. It also includes management of the agents and the principal interaction. While the operating activities are based on monitoring and managing maintenance, the maintenance activities itself are focused on providing routine observation, service and repairs (GL Garrad Hassan, 2013). In this research the focus is on the maintenance of the wind turbines of a wind farm excluding the foundation. It also includes all the offshore wind turbine maintenance logistics needed during its operational lifetime.

3.2.2 What is a windturbine?

Before zooming in on the O&M activities, it is important to understand the underlying technical components and their functions of the wind turbine. This will create more understanding of the impact of particular component failures and leads to solid background information.

A wind turbine can be categorized as an electro-aeromechanical conversion system. Roughly sketched, it consists of a rotor, nacelle with interior, a control and safety system and an electrical generator system (Schontag, 1996). The wind turbine and the support structure together can be summarized as a wind energy converter. Current wind turbines are available in a wide range from small near shore wind turbines (1-2MW) to very large sophisticated machines with a rated power more than 3 MW (DONG energy, 2016). The newest wind turbines can reach a 160m diameter and a tower height around 110 meters with a rated power of 8MW. In januari 2017 MHI Vestas Offshore Wind, a big turbine supplier with the headquarter in Denmark, unveiled its new 9MW wind turbine with 80 meters blades and even a possibility to transfer people by helicopter (MHI Vestas, 2017). In figure 14, the main components of a windturbine are sketched and explained to give some technical background before zooming in on the O&M activities.



Component	Goal
Rotor	Extracts kinetic energy from the wind and transforms it into mechanical energy.
Gearbox	Connects the main shaft and the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute to about 1,000-1,800. The gearbox is a costly heavy part of a wind turbine.
Generator	Converts mechanical energy to electrical energy.
Main shaft	Transfers the loads and transforms the power in order to drive the generator.
High-speed shaft	Shaft drives the generator.
Power control system	Limits and conditions the extracted power.
Tower	The wind turbine and transfers the rotor loads to the foundation.
Yaw system	Is used to turn the wind turbine rotor against the wind.

Figure (14). Main components of a windturbine. Hitachi, Schontag (1996), Dvorak (2016), Luminosity Engineering Technologies.

In the following diagram a decomposition of the total Offshore wind energy converter is shown.

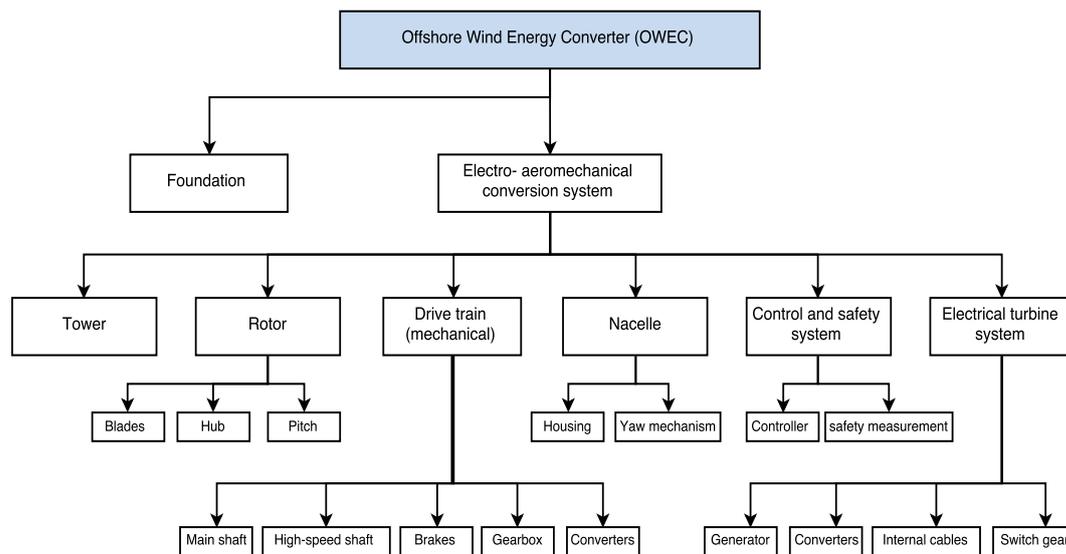


Figure (15). The Offshore Wind Energy Converter. Schontag (1996), Dvorak (2016), Luminosity Engineering Technologies

Of course the current wind turbines are available in a very wide range from small to big machines and from near shore types to deep-sea versions. Also there is range of different foundation types such as the monopile, gravity-based foundation, tripod and jacket foundation. The variable foundations are not in scope of this research so no further details will be examined. As the offshore wind farm logistic variables such as distance from shore, average sea state and the depth where relatively easy to define, the wind turbine variables are more complex to categorize because there is an enormous variety due to different turbine manufacturers, different owner demands and different locations in the world. Though it is more efficient to look at the general cost drivers of the wind turbines. These essential cost drivers are the same for each type of turbine (Schontag, 1996). To grasp the bigger picture of the cost drivers in relation to the energy output, it is essential to understand the levelized cost of energy concept. This concept is further explained in the next paragraph.

3.2.2 LCoE offshore wind

Before diving into all the O&M activities of the offshore wind industry, it is important to get an understanding of the levelized costs of energy (LCoE) in the overall energy market. The key concept of the LCoE is the measurement of the lifetime costs divided by the total energy production. This means that it calculates the present value of the total cost of building and operating a power plant over an approximated lifetime (U.S Department of Energy, 2015). The LCoE is introduced to allow the comparison of different energy technologies such as natural gas, oil, solar and wind energy. These energy technologies have different life times, capital costs, risks, returns etc. The LCoE makes it possible to compare these energies because both lifetime costs and overall production output are included (U.S. Department of Energy, 2015).

The O&M costs result from operating and maintaining the system offshore wind farm. By increasing the O&M activities, the overall availability will be improved but the O&M costs will of course also increase.

Though, we have to keep in mind that the total availability not only depends on the operation and maintenance strategy but also on the reliability of the used wind turbines (Schontag, 1996, p.24). Because this research focuses on the O&M post-warranty future, it only highlights the revenue earned from improving the availability and it excludes the initial costs in earlier phases. In figure 16 the factors in the levelized cost calculation of the OWEC energy system are schematized (Vire, 2017). The goal during the O&M phase is to reduce the annual expenses and to optimize the annual energy production by increasing the availability. As shown in figure 16, the physical site characteristics have a big influence on the annual energy production.

A thorough insight into the activities affecting the O&M costs, the impact on the performance, and the O&M strategy is necessary to find the decision-making variables for the post-warranty future.

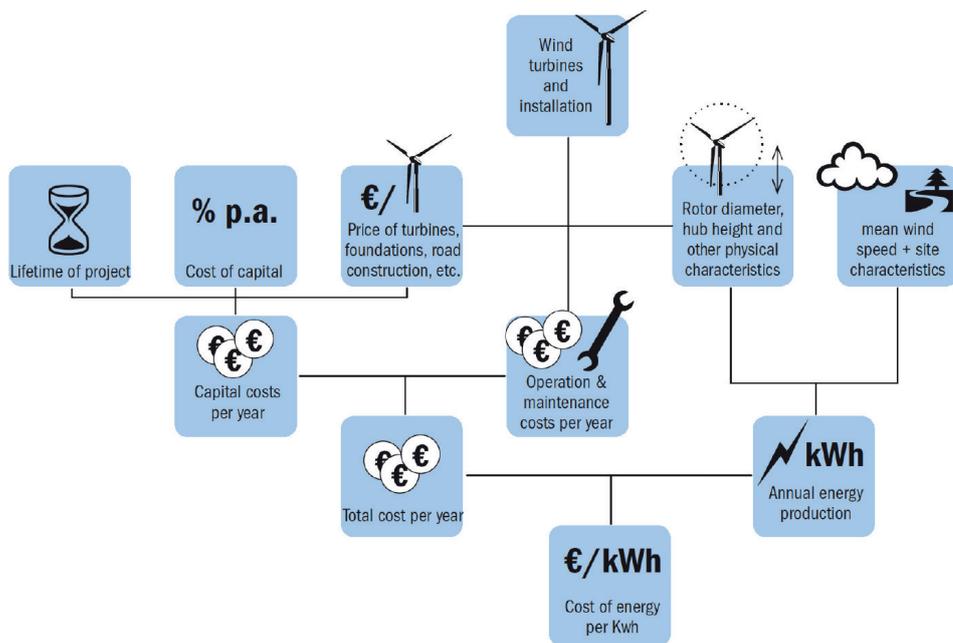


Figure (16). LCoE decomposition
 Vire (2017) Introduction to Wind Energy, Economic aspects

The formula used for calculating the LCOE of renewable energy technologies is shown below.

$$\text{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

LCOE = The average lifetime levelised cost of energy
 I_t = Investment expenditures in the year t (CAPEX)
 M_t = Operations and maintenance expenditures in the year t (OPEX)
 F_t = fuel expenditures in the year t (Wind energy $F_t = 0$)
 E_t = energy generation in the year t
 r = discount rate
 n = economic life of the system

Source: IRENA (2012). Cost analysis series, Wind Power

3.2.3 The performance indicator: Availability of the wind turbine

As shown in figure 16, the annual energy yield is influenced by the site characteristics and the physical characteristics of the wind turbine. When the turbines are technically able to operate, site conditions such as low wind speeds or icing may prevent power production, this aspect is not included in the notion of availability. In contrast, when conditions are good, technical failure may also restrict extraction of wind power. The latter is directly associated with availability and can be used as a performance indicator.

Hastings defines Availability as ‘the proportion of time for which a machine is available for use’ (Hastings, 2015). In this definition it is still questionable when a machine is ‘available for use’. The machine can be seen as ‘available for use’ if it is capable of performing its intended duty (Schontag, 1996). Here we assume that the necessary external resources are provided.

With this clarification the definition of availability in this research becomes:

‘The proportion of time for which a system is capable of performing its intended duty.’

In this research the ‘machine’ is the wind turbine, also called the Offshore Wind Energy Converter (OWEC). The *turbine availability factor* defines the expected average turbine availability of the wind farm over the life of the project. This factor is a percentage that accounts for the loss of energy associated with the amount of time the turbines are unavailable to produce electricity (Wind Energy, 2017).

The average availability is defined by the following formula:

$$A_{av} = \text{MTTF} / (\text{MTTF} + \text{MTTR})$$

In the average availability equation the MTTF is the Mean Time to Failure (h), which expresses the average operating time of an item, and MTTR is the Mean Time to Repair (h), which denotes the average time of restoration after failures (Puglia, 2013). The MTTR also includes downtime due to waiting for good weather.

The wind turbine can be seen as a repairable system with components that can fail at some point during its lifetime. The subcomponents can be also non-repairable systems that need to be replaced by a new system at some point. However the system in itself, the total wind turbine, can be brought back to an operating condition that matches the preferred performance during a certain point in its lifetime. This is linked to the normal degradation line.

When looking closer at the factors that define availability it becomes clear that not only the reliability and maintainability of the subcomponents have a big impact on the availability but also the offshore logistics play an important role because this defines the accessibility of the turbines (Schontag, 1996; Van Oord, 2017). So the availability can be illustrated by the following main factors.

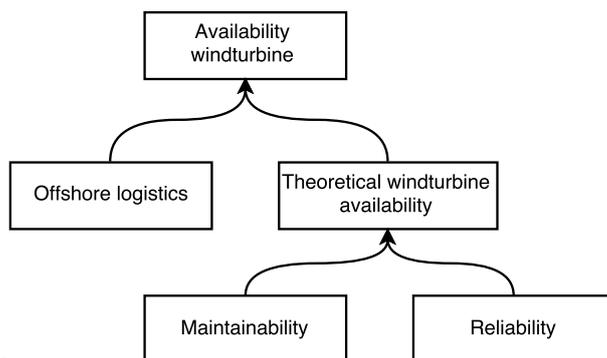


Figure (17). performance indicators

The tracking of failures and associated costs of repair or replacement allow for reliability analyses such as condition-based monitoring systems.

With the help of Pareto analyses the failures that require significant expenditures can be revealed. This reliability technique can contribute to this research because it is based on ‘the law of the vital few’. It focuses attention on the contributors to the causes that contribute most to the effects (Hill et al., 2008). These effects such as downtime, unavailability and eventually high O&M costs, have a big impact in the O&M contracting strategy.

Pareto analysis usually shows that 80% of the problems are caused by 20% of the initial causes. The following statement by Vilfredo Pareto is important to keep in mind while defining new O&M strategies based on the consequences of failures:

‘The consequences of all failures are not equal. Failure behaviour and repair actions will determine costs’ (Vilfredo Pareto, 1896).

Maintainability of windturbines

Maintainability relates to the ease or difficulty with which an item can be repaired when it fails (IEC 603003). The basic factor in maintainability is the MTTR.

Defined with a more formal measure, it is the proportion of repairs that are completed within a specified maintenance time constraint (Hastings, 2015).

Reliability of windturbines

For many assets the O&M phase is decades long. This means that this physical asset has to be maintained in such a way that it meets its performance targets while it has to survive in a dynamic world. As shown, the reliability and maintainability of the subcomponents have a big impact on the availability.

The reliability of an asset can be defined as:

‘The ability of an item to perform a required function under stated conditions for a specified period of time.’ (ISO55000)

The offshore wind industry accepted turbine lifetime around the 20 years. Here the availability of a turbine is the percentage of time that the turbine will be functioning at full capacity during appropriate wind conditions at a site with specified wind resource characterization for a 20-year lifetime (Hill et al, 2008).

The reliability can be graphically represented in a bathtub curve that describes the lifecycle of the turbine with the infant mortality period, the normal life period and an 'end of life wear out' period. As shown in figure 36 the bathtub curve of a wind turbine has a decreasing failure rate in the first period followed by a low and slowly increasing but relatively constant failure rate during the normal life and an increasing failure rate in the end of its lifetime. The normal life is not a perfect straight line due to cumulative changes of component failures when approaching the wear out period.

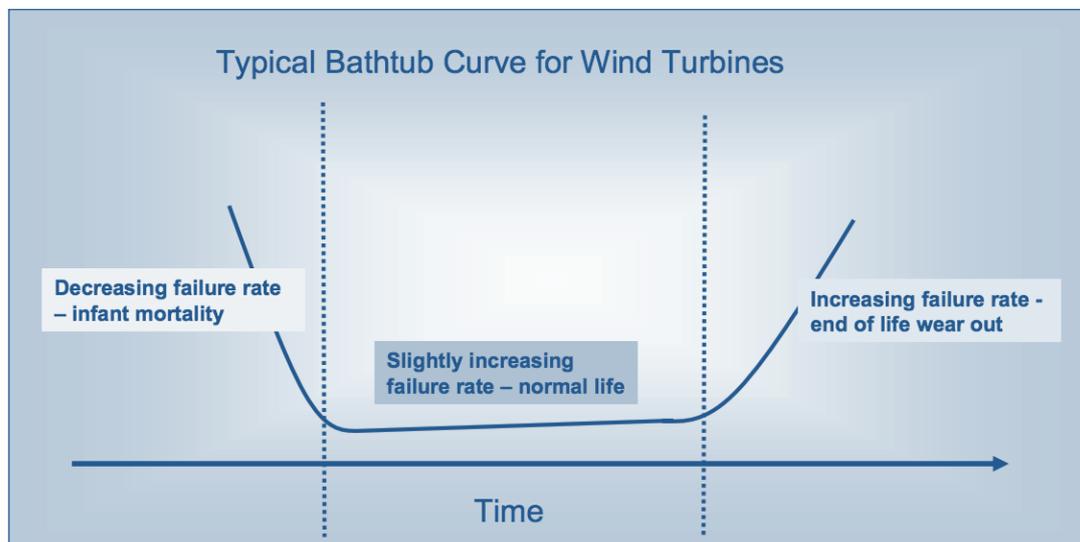


Figure (18). Bathtub for Wind Turbines. Hill et al (2008)

3.2.4 Condition based maintenance in the offshore wind industry

It is commonly known that there is a need to make judgments about the priority of activities based on the scheduled and unscheduled maintenance workload and weather forecast (GL Garrad Hassan, 2013)

In paragraph 3.1.1., corrective maintenance and preventive maintenance were identified as two different types of maintenance policies. Preventive maintenance aims to reduce the probability of failures and the corrective maintenance implies a maintenance action after the failure already occurred. In this section the focus is on preventive maintenance and in particular the condition-based maintenance.

In paragraph 3.1.2, condition-based maintenance was defined as a maintenance strategy that monitors the actual condition of the asset to decide what maintenance should be done.

To be even more precise in the definition it is important to include the prediction of the degradation process. Condition-based maintenance focuses on the prediction of degradation process of the product, which is based on the assumption that most abnormalities do not occur instantaneously, and usually there are degradation processes from normal states to abnormalities (Fu et al., 2004). So condition-based maintenance focuses not only on fault detection and diagnostics of components but also on degradation monitoring and failure prediction. This reduces the uncertainty of maintenance activities by enabling us to identify and solve problems in advance before product damage occurs which leads to a more asset specific strategy (Peng et al., 2010).

In the graph by Jardine and Tsang presented on the next page (figure 19), a gradual failure line is shown. On the vertical axis the condition is sketched and the horizontal axis shows the moment in time. The black line shows a total failure that decreases till it reaches zero, which means that a failure has occurred and corrective maintenance is necessary. The green line shows preventive scheduled maintenance, which leads to a lot of small maintenance interventions to keep the condition between set boundaries. The red line represents the condition-based maintenance. It shows that there is a lower minimal condition that is needed for the asset to function and when that minimal condition is approaching, preventive maintenance is scheduled and carried out.

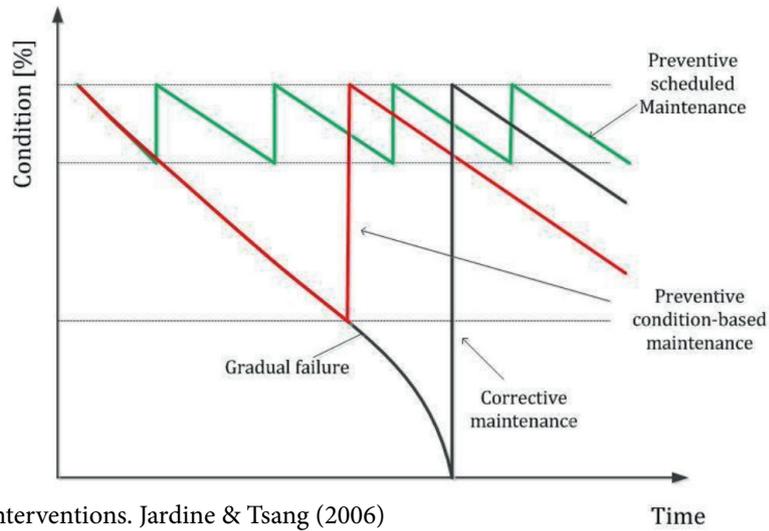


Figure (19). Maintenance interventions. Jardine & Tsang (2006)

For wind turbines the gradual failure lines are not that linear as Jardine & Tsang show due to an increasing degradation process just before a failure occurs. Interesting for this research are the costs associated with the different maintenance strategies.

In figure 20 by Tchakoua et al. (2014), the total costs, repair costs and prevention costs are presented in a graph related to the costs on the vertical axis and the number of failures on the horizontal axis. If a component shows almost no failures and is in a fine condition, preventive scheduled maintenance will lead to unnecessary high prevention costs. On the other hand, corrective maintenance will lead to high repair costs that could have been prevented in an earlier phase. Condition-based maintenance will try to find the optimum total costs by approaching an acceptable number of failures with an ultimate balance between prevention costs and possible repair costs.

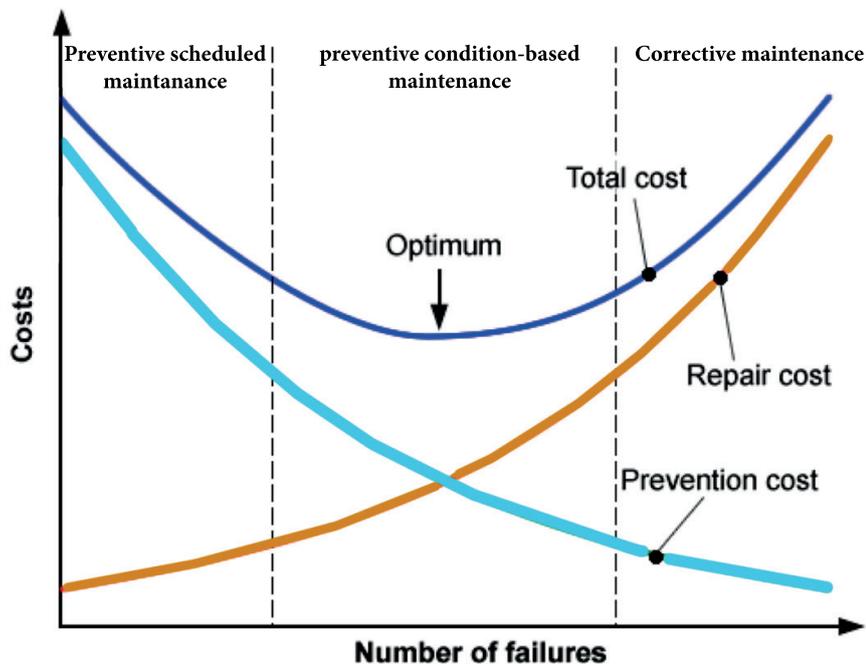


Figure (20). Economic optimization. Tchakoua et al. (2014)

Now we know more of the Levelized cost of wind energy, the performance indicators and the different types of maintenance, the next paragraph will focus on the O&M offshore activities that cause these O&M costs and drive the availability.

3.2.5 The activities within O&M of offshore wind turbines

In table 4 the O&M activities of a total offshore wind farm are listed including the goal of the activity, resources and current supplier. The seven main activities are grouped in supporting maintenance operations and asset specific maintenance. The asset specific maintenance activities are the maintenance activities that are directly related to the physical asset consisting of the foundation, turbine, grid connection and array cables. The supporting maintenance operations are the operation activities that are supporting the physical maintenance activities such as logistic activities, back office work and performance monitoring.

category	Activity	Sub-activities	Goal	Resources	Currently responsible
Supporting maintenance operations	Offshore logistics	<ul style="list-style-type: none"> •Crew transfer •Equipment & small delivery transfer •Planning & resources to move people & equipment 	Technician & equipment transfer and offshore accommodation to reduce transit time	<ul style="list-style-type: none"> •Various turbine maintenance vessels •Helicopters •Offshore accommodation/platform 	Owner/OEM
	Back office, administration and operations	<ul style="list-style-type: none"> • Control the condition measurement systems •Planning and scheduling activities •Service & fuel for vessels 	Provision of facilities from which to operate and monitor the wind farm	<ul style="list-style-type: none"> •Onshore O&M port •Skilled labour •Storing facilities 	Owner
	Onshore logistics	Shore side services: <ul style="list-style-type: none"> •Warehousing option and services •Onshore office logistics 	To provide supporting services such as bunkering, berthing and onshore transport options	<ul style="list-style-type: none"> •Warehousing •On-site office space 	Owner
physical asset specific maintenance	Export cable & grid connection	<ul style="list-style-type: none"> •Inspect and repair of the connection of the offshore power plant to the onshore power transmission system •Inspect and repair electrical substations and export cables. 	Maintaining the onshore substation connection and associated work, export cable and offshore substation connection.	<ul style="list-style-type: none"> •Offshore platform skilled labour •Onshore electricals •various cable repair vessels 	Offshore transmission owner (TenneT)
	Turbine maintenance	Predictive and preventive maintenance of the windfarm: <ul style="list-style-type: none"> •small & large component maintenance •replacements spare parts (blades, generators, gearbox). •Installing new monitoring technologies •Repeatedly preventive inspections •training of new technicians 	Keep up the performance and repair of the wind turbine	<ul style="list-style-type: none"> •Vessels for transportation crew & material •Offshore and near-shore operations vessels 	OEM/owner/ISP
	Array cable maintenance	<ul style="list-style-type: none"> •Array cable surveys and repairs 	Monitoring and surveying the cable condition and repairing when required	<ul style="list-style-type: none"> •Cable monitoring systems •Cable repair vessels 	Owner
	Foundation maintenance	<ul style="list-style-type: none"> •Foundation repairs •Structural and scour surveys •Lifting and climbing activities 	Mostly visual inspection and surveys to maintain the foundations structural strength, corrosion & scour protection	<ul style="list-style-type: none"> •Lifting & climbing equipment •Foundation maintenance vessel •Monitoring systems 	Owner/main design&Build contractor

Table (4). The O&M activities decomposition. GL Garrad Hassan (2013) & Vestas (2017)

The focus in this research will be on the three green highlighted activities.

Only the wind turbine excluding the foundation is part of the physical asset activities that will be further examined. The offshore logistics supporting the turbine maintenance are also part of the total maintenance activities of the wind turbine. The third activity is a maintenance operations activity and included in the research as ‘back-office, administration and operations’ category. This category can play an important role in this research because it includes the performance monitoring activities and the marine coordination that could have an impact on the M&O outsourcing strategy. When looking closer at these three main activities, a physical categorization can be found. The back-office maintenance operation activities are located onshore near the offshore site. All the turbine maintenance activities are offshore activities located at the offshore wind farm itself. Thirdly, the offshore logistics are the activities between that link the onshore back office activities to the offshore turbine maintenance activities. This categorization is shown in the figure below.

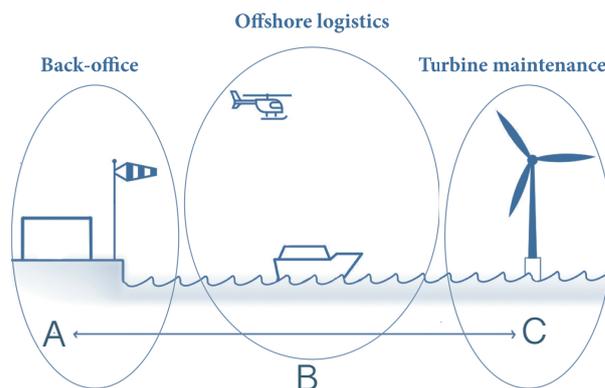


Figure (21). The main offshore wind activities. Own figure based on GL Garrad Hassan (2013)

A. Maintenance operations & back-office activities

The party that is responsible for managing the wind farm will undertake a number of management and back office roles. Where the goal of the maintenance activities is of course to keep up the performance and repair of the physical plant, refer the maintenance operations to the more high level management of the wind turbine such as coordinating, monitoring, administration and planning (GL Garrad Hassan, 2013). The maintenance operations cost drivers are marine coordinating, weather forecasting, condition monitoring and administration activities. These four activities are further explained in this sub-paragraph.

Marine coordinating

Marine coordination involves all day monitoring of the locations of all vessels and personnel within the scope of the project, including the interpretation of specialist tools such as marine coordination software (GL Garrad Hassan, 2013). From an onshore or offshore control room a marine coordination team takes the responsibility to ensure smooth. A high level of offshore logistics and marine knowledge is needed to carry the responsibility for ensuring that all statutory requirements at sea are met so people, materials and nature are protected (Deutsche Windtechnik). Marine coordination activities for offshore wind farms contain the following activities:

- Monitoring ship traffic and helicopters
- Communication and cooperation with parties in the maritime area via VHF radios
- Ship registrations
- Emergency assistance
- Operations planning
- People tracking
- Local marine knowledge

Source: SMC (2013) & Deutsche Windtechnik

Instead of only the offshore wind logistics, expert marine knowledge of all marine activities on site is important for delivering cost effective solutions (SMC, 2013). In the growing field of offshore wind, the integration with the older offshore industries becomes an interesting dynamic playfield. Communication and cooperation with other parties such as the Oil & Gas companies and the big offshore container transport companies could fill knowledge gaps and be an incentive for innovative partnerships.

Weather forecasting

Reliable weather forecast information enables efficient day-to-day planning and informed decision-making for offshore maintenance activities (Fugro, 2017). Offshore weather monitor stations can measure wind speed and direction as well as temperature and air pressure.

Accurate weather forecasting hours, days, and weeks ahead is an immensely important science to the offshore wind industry simply because the consequences have a direct effect on the costs.

Administration

As with any commercial activity, a lot of administrative activities must be completed in support of the offshore wind O&M. The following activities can be seen as administrative tasks:

- Financial supporting
- Public relations
- Procurement processes
- Human resources & training
- Parts and stock data registration
- Permit control
- Manage onshore back office facilities

Source: GL Garrad Hassan (2013) & Goldwind (2015)

Some of the administrative activities such as training personnel need to be carried out on offshore sites or onshore site facilities but the most back-office support activities can be done at a remote location such as head-offices.

Condition monitoring

Monitoring activities are generally performed by the turbine supplier and sometimes analysed in partnership with the wind farm owner. Specialist third parties or consultancies can also carry out the actual condition monitoring analysis. Next to the constant monitoring which requires several high skilled personnel, all the data can also be further analysed in depth for future condition monitoring purposes by the back-office staff and will eventually contribute to the total project management strategy (GL Garrad Hassan, 2013).

An essential element that safeguards the performance of a wind farm is the SCADA system. This system connects the individual turbines, the substations and the meteorological stations to a central computer that allows the operator to supervise the behaviour of all the wind turbines as a whole (Bachmann, 2014). It is a data-gathering system that can provide real time and historical information and can be accessed via software on the wind farm itself and or at onshore back office facilities. Normally each original equipment manufacturer has a proprietary SCADA system for its turbines.

In the following table the four main cost drivers of the back-office facilities are shown including the effect on the performance of the total wind farm and the possible risks.

Cost-drivers	Performance shapers (Effect on total availability)	Means	Possible risks
Marine coordinating	<ul style="list-style-type: none"> • Safety • Reliability • Downtime • Condition Measurability • Efficiency 	<ul style="list-style-type: none"> • Offshore facilities • Asset management personnel • R&D center • Condition monitoring equipment 	Asset management back-office failures
Weather forecasting			Lack of data
Administration			
Condition monitoring			

Table (5). Conclusion of the Back-office activities cost drivers

B. The offshore logistics

There are a lot of techniques and a wide range of equipment that can be used to support technicians in accessing offshore wind turbines. The primary goal of offshore wind logistics is to get people on and off turbines, as safely and as quickly as possible (Keseric, Statoil).

To move people and equipment from shore to the offshore plant requires equipment, resources including workboats, offshore bases, helicopters and jack-up services.

The following aspects are important:

- Transportation equipment & personnel
- Response time: availability of stock/equipment/labour and information transfer
- Safety measures: regulations and training
- Environmental impact: Site characteristics and wind turbine characteristics

The wind turbines need to be accessible to reduce unavailability leading to high maintenance costs. Because every wind farm has different characteristics, the actor responsible for the offshore logistics works with a logistic strategy that suite the specific plant. In the figure 22 presented below, the cost drivers of the offshore logistics are sketched.

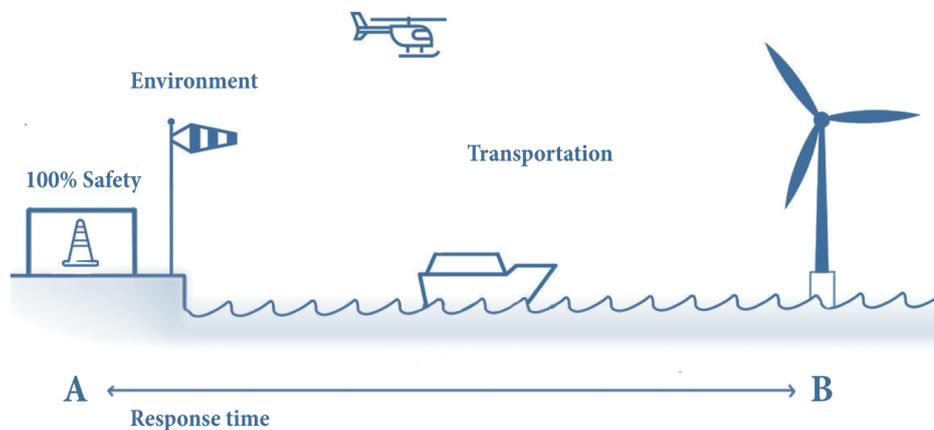


Figure (22). The main offshore logistics cost drivers

The above-mentioned factors are the main cost drivers for the offshore logistics activities and therefore influence the offshore logistic solutions. Of course these factors differ in every offshore wind project because all projects have different characteristics. The wind farm specific variables with the most impact on the offshore wind farm logistic strategy are listed below (GL Garrad Hassan, 2013):

Offshore wind farm logistic variables

- Distance from shore
- Average sea state: wave heights, currents
- Number, size and type of the turbines
- Reliability of the turbines
- Offshore substation design
- Depth: sea depth
- Environmental climate: wind speed, storms, lightning etc.

From these seven main characteristics, the distance from shore and turbine details have the most impact on the offshore logistic costs. When the wind farm is located far from shore, the response time, transportation costs and possible environmental impact on the turbines will increase.

Transportation modes and offshore facilities used to gain access to offshore turbines are workboats and the somewhat less well established helicopter services (GL Garrad Hassan, 2013; OWL, 2017)

In table 6 below, the current resources of the offshore logistic activities are presented.

means	subcategories	current providers	goal
Workboats equipment & people	Onshore based workboats (CTV)	Third parties or windfarm owner	•Transport people & equipment from shore to site (<50 km offshore distance)
	Offshore based workboats (SOV)	Third parties or windfarm owner	•Transport people&equipment from shore to site. •Transport people &equipment from offshore facilities to site. Lonterm stay of offshore crew on board (>50 km offshore distance)
Helicopters	Monitoring & crew transfer helicopters	Third parties (subcontractors)	•Transport personnel to and from the project site or support workboats
Crane barge services	Jack-up vessels	Third parties	•Floating wind farm service platform (incl cranes) for big component replacement & heavy lifting
Offshore accomodation base	Fixed/floating accomodation for people& vessel services	Owner/main DB operator	•Accomodation for if the project is located more than two hours transit by workboat from the O&M port. •The accomodation requires workboats or a helicopter to shuttle technicians and parts to the wind turbines.
Trained people	Trained people or third party expertise	Owner/contractor/third party	•Deliver maintenance activities and services

Table (6) Offshore logistic means. Sources: 4c Offshore (2017), GL Garrad Hassan (2013), OWL (2017)

The transportation method is a significant factor in achieving maximum usable wind turbines and reducing the time spent for travelling from and to the turbines (Schontag, 1996).

Travelling crews always have to be able to return safely to the base regardless of the weather condition. This state of the weather is one of the limiting factors while maintaining offshore wind farms. T Other transportation cost factors that have to be considered are initial investment and running costs of the transport device, the transport capacity and the modification costs that are needed to adopt the wind farm to the chosen transportation mode.

In the following table the four main cost drivers of the offshore logistics are shown including the effect on the performance of the total wind farm and the possible risks.

Cost-drivers	Performance shapers (Effect on total availability)	Means	Possible risks
Transportation	<ul style="list-style-type: none"> • Accessibility • Safety • Downtime 	<ul style="list-style-type: none"> • Transportation modes • Offshore facilities • Offshore personnel • Maintenance equipment 	Equipment failure
Safety measures			Unavailable transportation needs
Response time			Lack of crew knowledge
Environmental impact			High commodity costs (Oil, gas, metal etc.)
			Bad forecast

Table (7). Conclusion of offshore logistics

C. Turbine maintenance

The maintenance costs of the turbines, excluding the earlier mentioned offshore logistics, can be divided in material costs and personnel costs (Schontag, 1996). Closely related to these two cost types is the impact of marinisation. These three cost drivers will be further examined below.

Turbine maintenance material costs

Simple hand tools such as screwdrivers and socket sets are adequate for the performance of most preventive maintenance tasks. The crew does not need to carry these tools each time when accessing the wind turbine because a set of these tools could be stored on the turbine. If the often-needed equipment materials are stored on the turbine, crews could access the turbines without having to carry anything with them.

Quick access to necessary spare parts is an important factor that can reduce downtime costs of the turbine. Since the availability plays an important role in O&M contracts, downtime needs to be reduced as much as possible to achieve high availability of the turbine. According to Schontag (1996), the spare parts can be subdivided into three categories: Risk type items, repairables and consumables.

The risk type items have a low probability of demand but are expensive, essential and have a high delivery time (e.g. blades). Unlike the risk type items, the consumables have a high demand, low costs and a predictable consumption (e.g. oil, grease etc). The repairables are a different kind of spare part because these items can be repaired and brought back on site so no new item needs to be purchased.

The repairable items can also be complex technical components that have a high delivery time due to complex logistics, are essential and are not available in stock (e.g. gearbox). The following figure 23, presents the main categories of spare parts including the access to stock options.

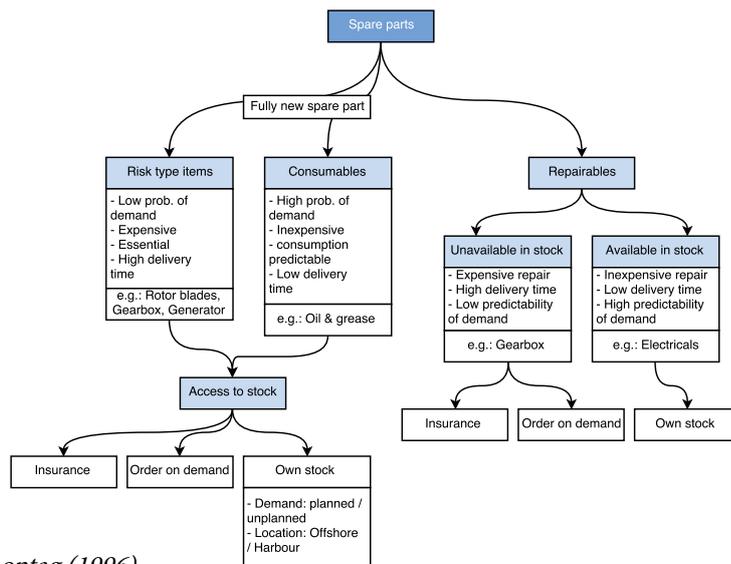


Figure (23). spare parts. Milborrow (2010) & Schontag (1996)

The downtime and costs related to the individual components are heavily influenced by the waiting time needed for lifting the components with good environmental conditions. Here the offshore logistics play a big part. In figure 24, Rademakers (2003) explained the costs and downtime for the individual components. As can be seen, the blade failure, generator failures and gearbox failures contribute together for over 75% of the costs and downtime. These components are the risk type items in figure 23. As this research aims at the exploration of factors that influence the O&M contracts, the absolute failure rate, λ , is not determinative. Besides, there are all

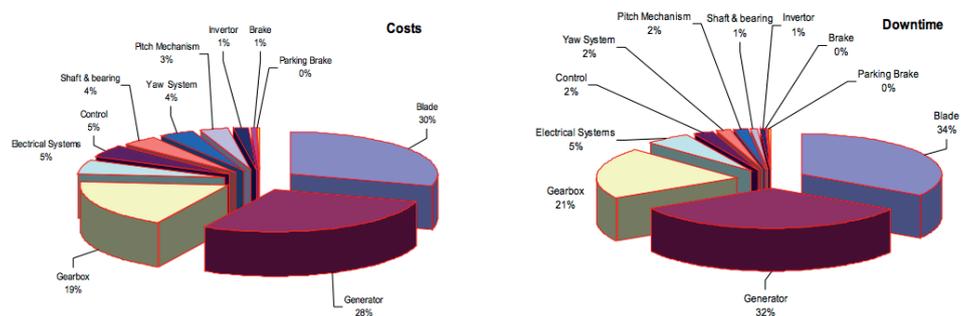


Figure (24). Relative contribution of the components to the costs and downtime. Rademakers (2003)

kinds of different offshore turbines with sometimes custom made components leading to all different kinds of failure types. Though it is possible to categorize the turbine maintenance activities that are needed to solve the consequences of failures. Rademakers defined four maintenance categories that can be linked to the offshore logistics and the failures leading to the turbine maintenance costs and downtime (table 8)

Category	Maintenance type	Transportation mode
1	Replacement of large lifting components: nacelle or rotor	External cranes: Jack-up vessels
2	Replacement of large components: single blades, gearboxes and generators	Internal cranes: crane vessel
3	Replacement of small parts	Workboats (SOV/CTV)
4	Inspection & repairs	Workboats (SOV/CTV)

Table (8). maintenance categories linked to offshore logistics. Rademakers et al. (2003)

Personnel

Personnel are needed for the preventive and corrective maintenance tasks at the wind turbines and for the overhaul of major components from the workboats to the wind turbine. The personnel that do the turbine maintenance during the warranty period will always be OEM personnel. These people are trained for specific technical labour on the OEM's turbine. During the actual turbine maintenance activities by people on a turbine, all safety procedures and requirements have to be taken into account. The costs of offshore work should not be underestimated. The additional costs of personnel permanently stationed on an offshore maintenance base have to be weighted against the reduced maintenance downtime costs due to a faster response time (Schontag, 1996). Also the high safety standards for people working offshore in a rough and dangerous environment are included in the overall cost per person.

The owner can also bring skilled labour in-house. If the owner aims to operate and maintain the whole wind farm in the future, it can train or hire new employees that can do specific offshore labour in the post-warranty period. Sometimes OEM's even help to train the owner's employees to hand-over knowledge about a specific wind turbine so joint turbine maintenance execution becomes possible (Operations, Vestas).

marinisation

Marinisation is the design of products specifically for use in the harsh marine environment. With a growing interest in the offshore wind industry and wind farms being build in deeper waters, there is a need to provide the industry with tools which can deal reliably with the complexity of combined wind and wave loading (Petersen et al., 1999).

Different environmental conditions have to be considered during the O&M of the offshore wind turbines. All the materials and equipment need to be resistant to the corrosive offshore environment to prevent fatigue crack growth (Schontag, 1996). All these investments that are made specifically for the use in the marine environment are a cost-driver that needs to be considered. The relevance for the O&M activities are the effect of corrosion and vibration that can create complexities during execution of O&M tasks. Here the weather conditions such as wind, rain and temperatures play major roles together with the sea state on site.

In the following table the three main cost drivers of the turbine maintenance are shown including the effect on the performance of the total wind farm and the possible risks.

Cost-drivers	Performance shapers (Effect on total availability)	Means	Possible risks
Material	<ul style="list-style-type: none"> • Safety:offshore site • Reliability • Maintainability • Downtime 	<ul style="list-style-type: none"> • Advanced control systems • Offshore platform • Trained people offshore • Maintenance equipment 	Access & availability of stock
Personnel			Skilled people
Impact marinisation			Downtime costs
			Component failure rates
			Marine environmental effects

Table (9). Conclusion of the turbine maintenance

3.3 O&M offshore wind in the Six stage model

In previous paragraph, the technical aspects of the wind turbine maintenance and offshore wind farms logistics during the operational lifetime were discussed. During the warranty period all O&M activities are outsourced to the OEM with ‘availability’ as the main performance shaper. Here the availability was derived from accessibility (offshore logistics), maintainability and reliability. During the decision-making period for the post-warranty future, owners are looking at the best O&M strategy. When looking at the main physical activities it was concluded that the total O&M outsourced activities can be divided in the actual turbine maintenance, the offshore logistics and the back-office maintenance operations. These activities and their main cost drivers are combined with the earlier discussed Six Stage model.

It became evident that these three physical activities may have dependencies. Although the availability performance output is the main indicator in the O&M contracts, the three main activities all contribute on different sub-indicators. The offshore logistics contributes mainly to the accessibility of the wind farm, the actual turbine maintenance contributes to the reliability and maintainability of the turbines and all the back-office maintenance operation activities contribute to the reliability and the condition measurability.

In figure 25 the three main activities and the performance indicators are used to categorize the three activities in the Six Stage Model. It is striking to see that all three activities have overlap in the ‘planning design’ and ‘data management’ steps.

This could entail that these steps in the Six Stage model are essential if the owner wants to scope the current performance based contract and wants to take specific steps in-house.

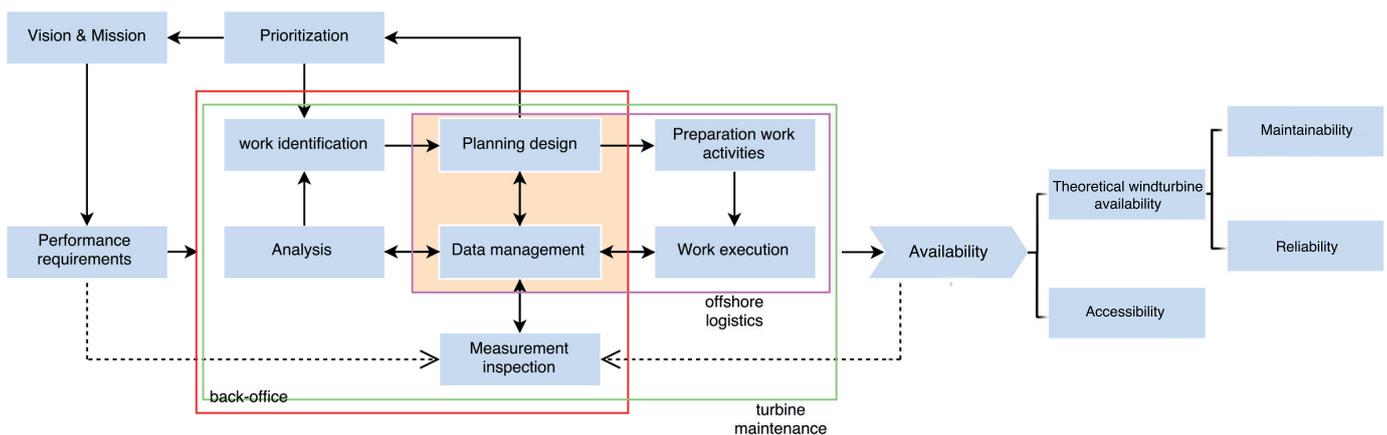


Figure (25). Six Stage model for windturbine O&M activities

All these three activities consisted of main cost-drivers and possible risks.

The O&M costs result from the total activities and resources that are needed for operating and maintaining the system. For the cost-based maintenance approach for offshore wind farms the O&M costs have to be weighted against the produced energy, and thus income, leading to the earlier discussed Levelized cost of Energy. Increasing the maintenance efforts will improve the overall availability of the wind farm but will also increase the required resources to be devoted to O&M (Schontag, 1996). This means that an optimization of the O&M costs is not achieved by a only the minimization of the O&M costs but rather a trade-off is required between the resources devoted to O&M and the extra revenue earned from improving the availability (Schontag 1996 & GL Garrad Hassan, 2013). Of course the long term-target of offshore wind farming is to produce energy at prices that are competitive to other sources of energy.

In chapter three the main cost drivers of the three activities where already defined and are now put together combined in one diagram. Other more operational expenses such as taxes, insurances and land rent are not included in this diagram and out of scope for this research.

As shown in figure 26, the maintainability, reliability and accessibility are linked to the O&M cost drivers and are eventually leading to the availability rate. The location of the wind farm and the weather, play the most important roles for the accessibility of the wind turbines. The risk type items (gearbox, generator and rotor), the offshore work hours and the heavy equipment are leading drivers for the maintainability of the wind turbine, discussed in the previous paragraph. The condition monitoring and performance measurement systems are essential to collect and interpret data to define the reliability of the turbines.

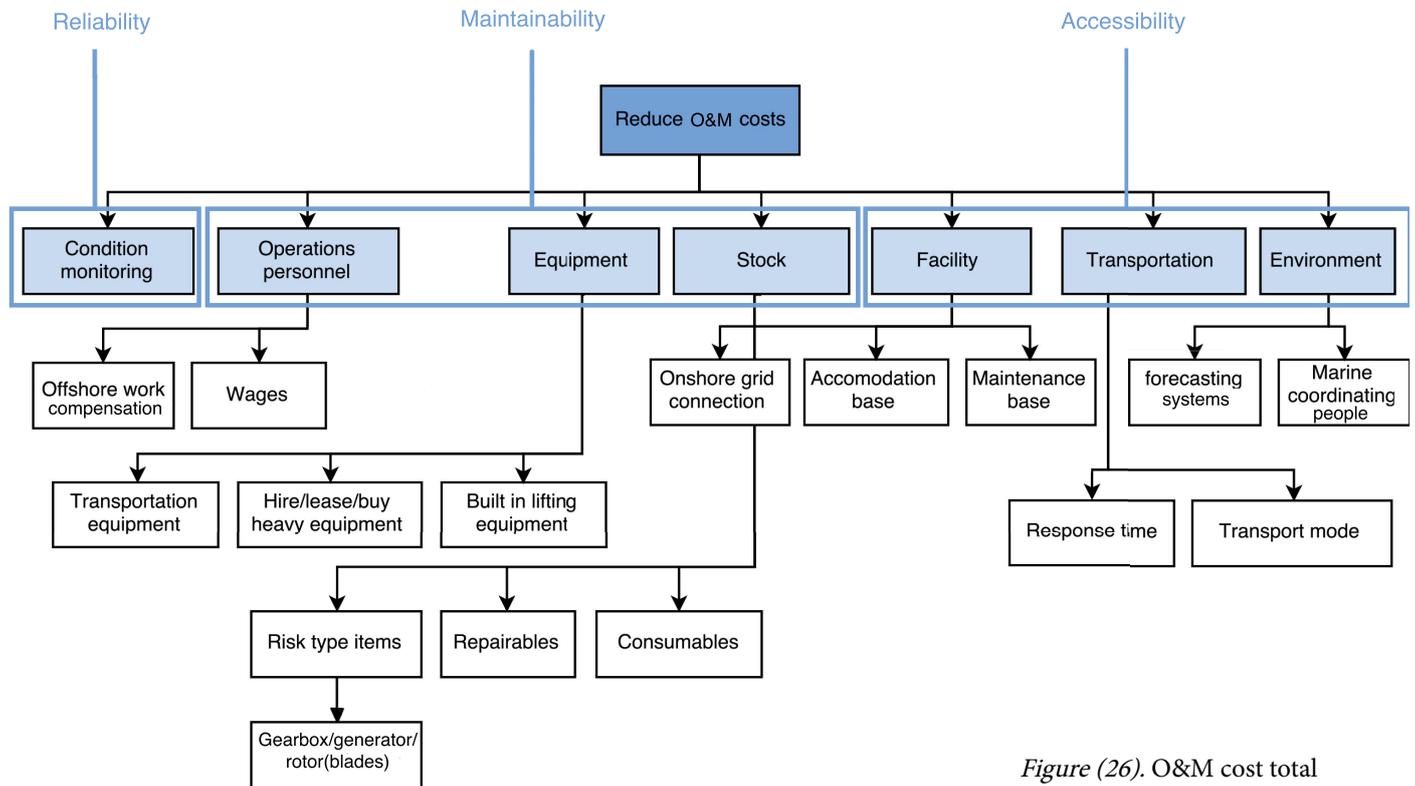


Figure (26). O&M cost total

All in all, in this chapter, the answer was given on the first subquestion:

- What are the main offshore wind farm O&M activities?
 - What are their cost-drivers?
 - What is their influence on the performance of the wind farm?

The main cost drivers of the activities are discussed and matched to the main performance shaper ‘availability’ of the wind turbine. Figure 25 and 26 together give an overview.

In the next chapter, the theoretical contract framework will be examined and measurable variables to scope the performance contract are gathered by using contract theory. The second sub-question will be answered in this chapter:

- Which contract theory variables are relevant in the decision-making process for a new sourcing strategy for offshore wind farm O&M?

Both these sub-questions are input for the decision-making framework and will eventually answer the main research question.

4. Theoretical contract framework

In this research the measurable variables to scope the performance contract is gathered by using contract theory. Contract theory is the study of the way individuals and businesses construct and develop legal agreements. It researches how parties make decisions to create a contract with particular terms in case uncertain conditions happen.

There are a few main theories in this field of study. In this research the focus is going to be on Transaction cost Economics (TcE) and the Principle-Agent theory. With these two theories the focus of the variables is divided in the following categories (Rossignoli & Ricciardi, 2015):

- o Transactions (market vs organization)
- o Contract (behaviour vs outcome)

The Transaction cost theory is focus on the 'transaction' and addresses the questions about why firms exist and how they define their boundary. This theory explains why activities are done within the company and why other activities are outsourced to other companies. In the agency theory the focus is on the contract type and the main question is about how to predict whether a behaviour-oriented contract will be more or less attractive and efficient than an outcome oriented contract.

4.1 Transaction Costs Economics theory

Organizations are driven by the need of reducing costs when interacting with each other. According to this theory the main focus is on the transaction.

According to Williamson in 1985:

'A transaction occurs when a good or service is transferred across a technologically separable interface. One stage of activity terminates and another begins.'

This theory addresses the questions about why firms exist and how they define their boundary. Without the 'technologically separable interface' no real transaction occurs which means that the service or good is not transferred but still in-house.

The theory focuses on why it is sometimes beneficial to produce parts of an asset yourself and why it is sometimes more likely to outsource an activity to another organization. Coase (1937) identified two conceptual categories: The market exchange and the firm's internal transactions. Coase studied when certain economic tasks would be performed by firms and when would they be performed on the market. Here arises a managerial choice between either market or hierarchy (Fox, 2014). Coase stated that firms exist because going to the market all the time can impose heavy costs (later known as the 'transaction costs') due to for example negotiation time, creating new contracts and to hire experts for these activities.

So eventually in 1970 he already attempted to put forward the view of the price mechanism's role as an organizational tool, which is the start of the transaction cost theory. In that time also Kenneth Arrow already defined transactions costs as the 'cost of running the economic system' (Arrow, 1969), that can impede and sometimes even block the economic system.

Williamson's way of thinking in the 70ths was influenced by Coase and other authors that preceded him. He emphasizes the fact that organizations always try to find the most efficient boundaries of their organization with make-or-buy decisions. These boundaries can divide markets from hierarchies and visa versa. In 1985 Williamson explained his 'efficient boundary theory' with an illustration of the production process in three 'stages' where decisions have to be made between 'make' or 'buy', including the 'resources', 'components' and 'distribution'. Every separable stage of production is one for which a careful assessment of make-or-buy is warranted (Williamson, 1985. p.96).

Suppose that the input are the raw materials and in each stage there is a physical transformation where the components can be made or bought and become connected to the mainframe. Eventually the firm can use own distribution or can use market distribution.

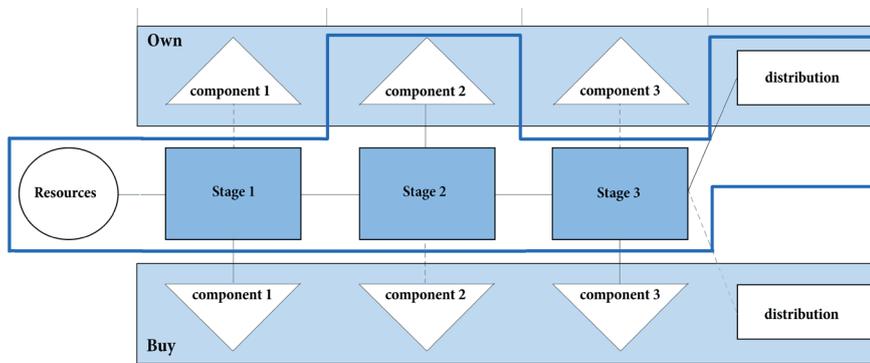


Figure (27). Efficient boundaries. Williamson (1985)

In the figure 27 illustrated above Williamson’s ‘efficient boundary’ theory is shown. The solid lines between units represent actual transactions and dashed lines a potential transaction

In this particular case, an organization is illustrated that leaves component 1 and 3 to the market and only makes component 2. In figure 27 the organizational boundaries of the wind farm O&M contractor include the in-house knowledge and original equipment (resources) that are used to plan and maintain the wind turbines. While working with this framework it is important to keep in mind that the ‘efficient boundary’ theory is limited because it is oversimplified. In reality the process stages are not fully transferred to the market or to the organization because for example a contractor has overlapping interfaces with the client. This leads to vague boundaries instead of the clear efficient boundaries.

In this research the transaction cost categories will be separated in ex-ante and post-ante transaction costs to include both the process just before the decision-making and the possible consequences just after a contract is implemented. Hughes et al. (2006) defined four stages that together with the categorizations of Dahlmann (1979, p.147-148) and Gruneberg & Ive (2000) are the input for the following main transaction costs categories used in this research.

Transaction cost categories			
Ex-ante TC	1	Information gathering costs	Market analysis, data gathering, pre-qualifications
	2	Bargaining costs	Finding possible acceptable agreements by estimating, bidding and/or negotiating work
	3	selection procedure costs	Assessment, calculations, fixing price, actual decision making, contract comes into being
Ex-post TC	4	performance monitoring costs	Managing the realization of the contract and ensure other party sticks to the terms
	5	contract enforcement costs	Taking appropriate actions if there are disputes

Table (10). Transaction cost categories. Hughes et al. (2006); Dahlmann (1979, p.147-148); Gruneberg & Ive (2000)

Williamson emphasized the fact that it is crucial for organizations to define the critical transactions (Williamson, 1985). This critical transaction will eventually influence the decision of which alternative transaction governance system to use between hierarchy, market or a mixed version. According to Williamson these critical transactions factors could be divided in human factors and environmental factors resulting in the sub-identification of four reasons why transaction costs arise (Rossignoli & Ricciardi, 2015).

These four critical transaction factors are discussed in the next paragraph.

4.1.1 Critical transaction factors

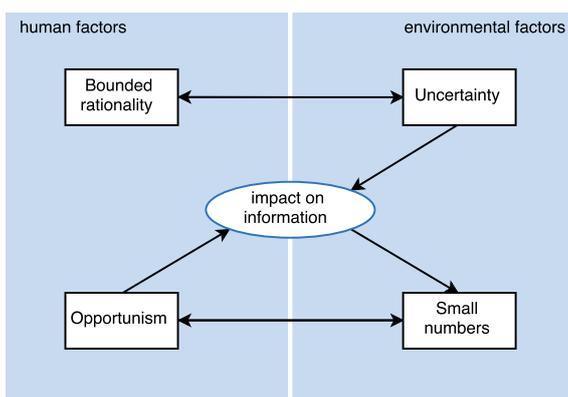


Figure (28). the organizational failure framework. Rossignoli & Ricciardi (2015) & Williamson (1975)

Williamson states that the goal of an organization is to minimize the costs of exchanging resources in the business environment and the costs of managing exchanges internally in the organization. In figure 28 the critical transaction factors are schematized and organized in human factors (internal) and environmental factors (external) according to Williamson’s theory. In the centre the impact on information is illustrated. Here ‘information impact’ is defined as the phenomenon when one group has better understanding or more information about an exchange than another party, which results in known or unknown (dis-) advantages.

Bounded rationality

Transaction cost Economics assumes that the sphere of human knowledge is rational but bounded in its intentions (Simon, 1996). Simon emphasises that most people are only partly rational because they are limited in formulating, solving complex problems and processing information. Simon suggests that economic agents use heuristic techniques to make decisions rather than rigid rules of optimization. With heuristic techniques defined as an approach to problem solving that employs a practical method not guaranteed to be optimal. Examples of those practical methods can be rule of thumb, intuitive judging or educated guesses. It can be concluded that the bounded rationality theory is a human critical transaction factor.

Opportunism

Williamson suggested that opportunism emerges as the source of the transaction costs involved in monitoring and enforcing contracts (Hodgson, 2004). With this opportunism people lie, mislead, steal, cheat and act differently than expected. The opportunism theory is like the bounded reality theory, a human critical transaction factor. People act in a self-interested way, which according to Williamson is the problem of the 'self-interest seeking with guile'. It means that 'trust' becomes an important factor within the transaction because agents may serve their own interests rather than those of other parties resulting in untrustworthy relations. Here he defines trust as 'a bet about future contingent actions of others'. According to Williamson trust is excluded from the Transaction cost Theory because he claims that in a world of opportunism people cannot be assumed to keep their promises and to fulfil their duties unless "safeguards" are in place (Williamson, 1985, p.32).

Environmental uncertainty

The uncertainty factor derives from opportunism and bounded rationality. Uncertainty is seen as a more environmental factor because it includes the dependency on the market. Here we see that the uncertainty is influenced by the both complexity of the environment and the fact that other parties might show opportunistic behaviour. Also the bounded reality theory will enforce this uncertainty because the economic agents only can use heuristic techniques. The higher the environmental uncertainty, the higher the transaction costs to implement the exchanges (Rossignoli & Ricciardi, 2015). Williamson himself builds his uncertainty theory on Koopmans (1957) who distinguished between primary and secondary uncertainty as follows: 'primary uncertainty reflects a lack of knowledge about states of nature, such as the uncertainty regarding natural events, whereas secondary uncertainty reflects a lack of knowledge about the actions of other economic actors'. Koopmans' primary and secondary behaviour theory leads, according to Williamson, to possible strategical behaviour that he defines as 'behavioural uncertainty'.

Small numbers

As already explained, opportunism allows for strategic thinking and we often get guile in exchange. With large numbers of exchangers one could avoid or punish those who exhibit opportunistic behaviour but in situations of small numbers of exchangers it is difficult to avoid. In that case the advantages of the hierarchy are greater than those of the market (Rossignoli & Ricciardi, 2015). This phenomenon is defined as the critical transaction factor of 'large numbers' (Williamson, 1985). In the ex-ante transaction phase small number bargaining make it costly for parties who enter into economic relationships to leave them because the optional environmental attached strings become limited.

4.1.2 Critical dimensions that identify a transaction

Next to these four critical transaction factors Williamson described two main types of costs: transaction costs and production costs. Transaction costs and production costs are described as mutually exclusive factors that have the same rate of replacement (Rossignoli & Ricciardi, 2015). By evaluating the weight of both types of costs the best alternative between hierarchy and market can be evaluated. Williamson explains that both cost groups change when the specificity of the asset, the frequency of the transaction and the uncertainty vary that identify the single transactions. Between the two ends of the 'market' and 'hierarchy' spectrum, all intermediate situations can lead to different 'governance-by-contract' solutions. The hierarchy has higher fixed costs because there is an increased number of a transaction, which means that the hierarchical costs of use are spread over more than one transaction, resulting in a more efficient internal organization. The market has

higher variable costs due to the fact that in a market contracts have to be controlled, information has to be searched and negotiation procedures will take time and effort (Rossignoli & Ricciardi, 2015). This spectrum draws the organizational boundaries. Considering the 'critical dimensions' of asset specificity and transaction frequency, Williamson defined four main forms of transaction governance:

- Market – low transaction frequency and low investment in asset specificity.
- Trilateral Governance – a 'third-party' existed market that has a bureaucratic mechanism in addition to an external market.
- Bilateral Governance – The parties are to an extent locked-in and are sometimes forced to cooperate with the use of social factors as for example 'reputation'
- Hierarchy – high transaction frequency and high asset specificity.

Asset specificity

'Asset specificity' is a particularly important critical dimension according to Williamson. He defines asset specificity as:

"... durable investments that are undertaken in support of particular transactions, the opportunity cost of which investments is much lower in best alternative uses or by alternative users should the original transaction be prematurely terminated." (Williamson, 1981)

This definition could describe a variety of relationship-specific investments that are needed to execute the actual transaction. These costs are not only focused on the physical asset but could also include more intangible costs like for example specific knowledge gaps or possible R&D investments. The higher these durable investments, the more the transaction parties want to continue the relationship. Asset specificity occurs when the possible exchange requires specific investment or specific know-how to implement a certain contract. Asset specificity can take different forms including (Pint & Baldwin, 1997, ch.2): Location specificity to economize transportation costs, physical asset specificity regarding equipment, human capital specificity, dedicated capacity (serve a customer who is relatively large in the market so that it becomes difficult to find alternative customers) and brand name capital (must maintain the reputation of a shared brand name). The capability of markets to handle asset specificity can be limited by bounded rationality because the supplier and the seller cannot foresee all possible consequences (Pint & Baldwin, 1997, ch.2).

Frequency of the transaction

The frequency of the transition comes intuitively and is very much linked to the asset specificity. The degree of asset specificity depends on the degree of its utilization (Wengler, 2005, pp. 111-112). Frequent transactions and recurrent exchanges that are expected lead often to opportunistic behaviour because knowledge is built between the two parties. But if the transactions are recurrent, only fully used capacity of specialized assets will result in a greater benefit so opportunistic behaviour will not have a negative influence.

The frequency of the exchanges has an effect on both the internal and environmental transaction costs. Frequency can lower the internal production costs by having a positive effect on the production and the enabling of administrative economies of scale. It has also a positive influence on the environmental transaction costs because it creates the possibility to check the status of opportunism of previous transactions.

Uncertainty of the transaction

Williamson already defined 'uncertainty' as a critical transaction factor deriving from bounded rationality and opportunistic behaviour. As Koopmans defined primary and secondary uncertainty, Williamson added the behavioural uncertainty. If we look at the critical dimension of uncertainty effecting a single transaction it can be concluded that uncertainty itself is of little consequence if the transaction is non-specific (Williamson, 1985). This means that as long as trading relations can be easily fixed, the problem of uncertainty will be less because these relations can pursue market exchange (Wengler, 2005, p111). Williamson stated that an adequate mechanism to overcome uncertainty despite the presence of transaction specific assets could be 'adaptive, sequential decision-making', because it helps to diminish behavioural uncertainty even when there is an increasing degree of uncertainty (Williamson, 1985). According to Houlding (2008), 'decision-making with adaptive utility' allows the creation of a normative theory for decision selection when the preferences are initially uncertain. It is based on the classical Bayesian decision theory, which tries to quantify the trade-offs between decisions using probabilities and costs.

4.2 The Agency theory

Organizations are driven by the need of aligning the behaviours or outcomes of the other parties to expectations. In the Agent theory the main focus is on the contract instead of on the transaction in the Transaction cost theory. The Agent theory is rooted in the original studies on risk sharing among individuals and groups published by Arrow (1971) and Wilson (1968). Agency theory broadened the risk-sharing literature to include the agency problem that occurs when cooperating parties have different goals, interests and division of labour (Jensen & Meckling, 1976). The agency problem occurs when one party (principal) delegates work to another party (agent) who performs the work. Performance of this service leads to the delegation of a part of the decision-making authority to the agent. The responsibility transfer by the principal and the including division of labour can help to promote the efficiency and a productive economy (Eisenhardt, 1989).

The agency theory is focused on two contract problems that can occur in the relationship (Eisenhardt, 1989):

- Agency problem: Arises when the desires or goals of the principal and agent are conflicting. At this point it becomes difficult for the principal to verify what the agent is actually doing, which eventually could drive up costs. The problem here is that the principal cannot verify that the agent has behaved appropriately.
- Risk sharing problem: Arises when the principal and agent have different attitude towards risk. Due to different risk preferences the principal and the agent may prefer different actions

These two propositions define the key question in the Agency theory:

How can we predict whether a behaviour-oriented contract will be more or less attractive and efficient than an outcome oriented contract? (Eisenhardt, 1989)

According to Jensen and Meckling, behaviour-based contracts refer to contracts that remunerate supply chain managers based on observable performance measures.

They define outcome-based contracts as contracts based on the outcomes of agents behaviour.

The underlying discussion here is that whenever it is difficult to verify agents behaviour using objective performance measures, principals have the option to reward agents based on the results of their effort (Gomez-Mejia & Werner, 2008). There is only the problem that outcomes may be affected by other environmental factors that are beyond the agents direct control (i.e. political changes, economic climate, competitor's action etc.). Here key assumptions about people and organizations have to be researched including self-interest, bounded rationality, risk aversion and goal conflict. These factors are partly already discussed in the transaction costs theory (Rossignoli & Ricciardi, 2015). The essence of principal-agent theory is the trade-off between the cost of measuring outcomes and the cost of measuring behaviour and transferring risk to the agent. If the principal knows what the agent has done given the fact that the principal is buying the agent's behaviour, then a contract based on behaviour is most efficient. When the principal does not know exactly what the agent has done given the self-interest of the agent, the agent may or may not have behaved as agreed.

4.2.1 Critical factors of the Principle-agent theory

In the next paragraph the critical factors of the principle-agent theory and the effect on the relation are further examined.

Information asymmetry

Information asymmetry indicates that one party in a transaction process has relevant information whereas the other party does not. Looking back at the First Theorem of Adam Smith's famous work 'An Inquiry into the Nature and Causes of the Wealth of Nations' (1776) a confirmation of the 'invisible hand' hypothesis is given. This First Theorem indicates that 'competitive markets tend toward an efficient allocation of resources'. It states that with no externalities, prices would adjust so that the allocation of resources would be optimal in the Pareto sense. Here the 'Pareto optimality' of Vilfredo Pareto (late 19th) is a state of allocation of resources from which it is impossible to reallocate. A key assumption of the First Theorem is that all products traded on the market should be equally observed by all agents. When such assumption fails to hold it means that the information

is asymmetric. Information asymmetry leads to distorted prices and no optimal allocation of resources (Do, 2003). The effects of information asymmetry are adverse selection and moral hazard. When two individuals are agreeing on a specific trade and one of them happens to have more or different information than the other party does not have, this situation is called adverse selection. For example, a trader with more private information about the quality of a certain product will selectively participate in trades that have the most benefits for him. Moral hazard describes a situation where there is a hidden action that results from the transaction instead of the adverse selection where the type of product or service is hidden from one party in a transaction. In the case of moral hazard the information asymmetry occurs after an agreement is obtained between the two parties. For example, when selling health insurances, the buyer is more likely to behave recklessly because he has a health insurance.

Risk aversion

According to Eisenhardt the risk aversion of the agent is positively related to behaviour-based contracts and negatively related to outcome-based contracts. Here the behaviour-based contract is based on the observable performance measures and the outcome-based contract is based on the outcome of the agents behaviour. As the agent becomes less risk averse, it is more attractive to pass risk to the agent using outcome-based contracts because the agent is more confident that he is able to bare the risk. If the agent becomes increasingly more risk averse, it becomes expensive to pass risk to the agent so a behaviour-based contract is a better solution.

When looking from the principal's perspective, a similar kind of situation occurs. The risk aversion of the principal is negatively related to the behaviour-based contracts and positively related to outcome-based contracts (Rossignoli & Ricciardi, 2015). According to the agency theory, a contract based on outcome helps align the interests of the principal because the defined outcome is closely linked to what the principal explicitly wants. On the other hand, if the agents remuneration is based on outcomes, they bear risk due to outcome uncertainty and therefore would want to be compensated for bearing this risk (Gomez-Mejia & Werner, 2008).

Goal conflict

The agency problem occurs when the principle delegates work to the agent who performs the work. They become engaged by a contract but have different goals and different attitudes towards risk. The agency theory attempts to describe the problem of risk sharing when both parties have different attitudes and goals towards these risks. Actually the 'contract' is used as a metaphor to describe the 'relationship' of the two parties (Jensen & Meckling, 1976). The problem not only arises when the goals and desires of both parties differ but it is also difficult and sometimes expensive to verify what the other party in the relationship is actually doing. Without the knowledge of the activities and attitude of the other party, it becomes difficult to find the possible mismatch when finding a common goal. It also becomes difficult to verify possible undesired behaviour from one of the parties if a clear common goal is missing. Different goals and risk preferences can lead to complicated regulations, a lack of leadership, impression management, whistle-blowing and even possible compensation costs (Eisenhardt, 1989).

Outcome uncertainty

Outcome uncertainty will lead to difficulties in predicting the expected performance, which means that it is negatively related with the outcome-based contracts. When the expected outcomes are not clear, an outcome based contract will not fit, because the quality of verifying the agents objective performances with performance measurement techniques can not be guaranteed.

There are four factors that can lead to outcome uncertainty:

- Outcome measurability
- Length of the agency relationship
- Task programmability
- External factors (politics, climate, economy, society etc.)

If the uncertainty about future events and the uncertainty about the influence of the agent's behaviour on the outcome are substantial, the cost of risk transfer to the agent will increase due to more risk aversion (Schoenmaker, 2011).

Efficient ways of contracting according to the Agency Theory

After verifying the critical factors of the Agency theory, the next step is to look at efficient ways of contracting that consider these critical factors. Eisenhardt defined eight propositions that according to her could influence the contract decision-making based on the agency theory (Eisenhardt, 1989):

- 1) When the contract between the principal and agent is outcome based, the agent is more likely to behave in the interests of the principal.
- 2) When the principal has information to verify agent behavior, the agent is more likely to behave in the interests of the principal.
- 3) Information systems are positively related to behavior-based contracts and negatively related to outcome-based contracts.
- 4) Outcome uncertainty is positively related to behavior-based contracts and negatively related to outcome-based contracts.
- 5) The risk aversion of the agent is positively related to behavior based contracts and negatively related to outcome-based contracts.
- 6) The risk aversion of the principal is negatively related to behavior based contracts and positively related to outcome based contracts.
- 7) The goal conflict between principal and agent is negatively related to behavior based contracts and positively related to outcome based contracts.
- 8) Task programmability is positively related to behavior based contracts and negatively related to outcome-based contracts.
- 9) Outcome measurability is negatively related to behavior based contracts and positively related to outcome-based contracts.
- 10) The length of the agency relationship is positively related to behavior-based contracts and negatively related to outcome-based contracts.

After the description of the four main critical factors of the agency theory and considering Eisenhardt's efficient ways of contracting, the following step is to combine this knowledge for further use in this research. The essence of this theory is the trade-off between the cost of measuring outcomes and the cost of measuring behaviour and transferring risk to the agent.

If you choose that the costs of monitoring the information asymmetry needs to be less than the costs of outcome uncertainty, the contract will tend towards behavioural based. If you prefer lower outcome uncertainty costs and accept higher information asymmetry costs, the outcome-based contract will be the best option.

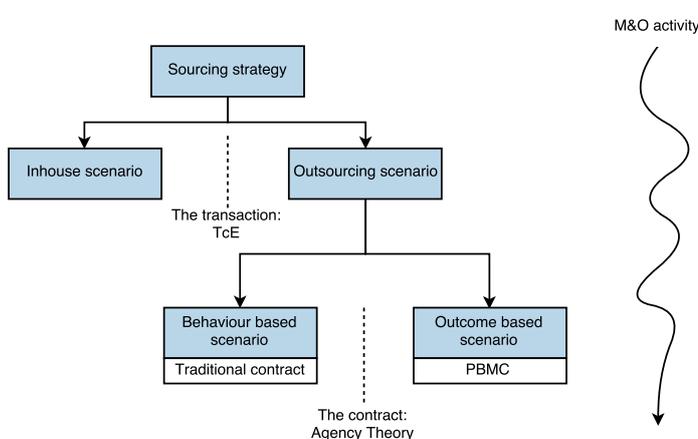
4.3 The theoretical sourcing framework

When describing the characteristics of the different activities within the O&M phase, it is more clear to create an order based on the dimensions of the transaction cost theory and the relation with the agency theory.

These main critical dimensions that affect the transaction are described as asset specificity, frequency and uncertainty. These dimensions are based on the internal and environmental critical transaction factors consisting of bounded rationality, opportunism, environmental uncertainty and the theory of small numbers. In the agency theory the main question is about how to predict whether a behaviour-oriented contract will be more or less attractive and efficient than an outcome oriented contract. The critical factors that were defined consisted of information asymmetry, risk aversion, goal conflict and outcome uncertainty.

In this paragraph both theories will be combined to create categories that can be used when defining the scope of performance-based contracts for offshore wind farms.

So the categorization is based on the characteristics of a transaction and the characteristics of the contract. These decision-making characteristics together with the cost drivers of the O&M activities and the effect on the performance, will lead to the decision-making framework.



In figure 29, the possible sourcing scenarios are shown in a simplified overview. Here you see that the transaction cost theory first defines the boundaries of the owners firm (in-house vs outsourcing) and if activities are outsourced to other contractors, the Agency theory can define if these activities should be outsourced with a traditional behaviour-based contract or a performance based contract.

Figure (29). Rough sketch of the possible sourcing scenarios

4.3.1 Combining the contract theory factors to structure possible sourcing scenarios

According to the efficient ways of contracting of Eisenhardt, the risk aversion of the principal is positively related to an outcome-based contract. Secondly, the goal conflict between the principal and the agent is also positively related to the outcome-based contract.

The risk aversion and goal conflict are both closely related to the critical factor of information asymmetry. A high information asymmetry leads to distorted prices and no optimal allocation of resources (Do, 2003). As an effect, adverse selection can occur, which means that the principal could agree on a specific trade without knowing all needed information. In this case the risks are increasing for the principal, which leads to an inequality of risk sharing. When the two parties have different attitudes and goals towards these risks, a goal conflict can occur.

Information asymmetry, goal conflict & risk aversion of the Agency theory are all related to the quality or state of the information that needs to be known when the principal delegates work to the agent and risks need to be shared.

In the Six Stage model, the information input for an performance-based contract are the performance requirements. The information output is the final performance of the system. According to this model, the actual performance output needs to be measured to create a feedback loop to the performance requirements (Schoemaker, 2011). This step in the model shows that the performance should be known if you want to choose a performance-based contract. The characteristics of the Agency theory can be used to identify whether the quality of the information about the performance is enough to enter into an outcome-based contract model. The quality or state of the performance information being known will be called 'knowability of performance'

and will be used in this research as one of the variables to structure the future sourcing scenarios.

The fourth critical factor of the Agency theory, outcome uncertainty, can lead to difficulties in predicting the expected performance, which means that it is negatively related with the outcome-based contracts. As described in paragraph 4.2.1, the four variables that can lead to outcome uncertainty are the length of the agency relationship, task programmability, outcome measurability and external factors (politics, climate, economy, society etc.).

As described in paragraph 3.1.3, different maintenance strategy researchers such as David Sherwin (2000) emphasized the fact that O&M activities have three main cyclic processes (Schoenmaker, 2011; BSI, 2004a, 2004b). The Six Stage model includes the first two cyclic processes. Here the first cyclic process only comprised routine maintenance activities and the second cyclic process comprised all maintenance activities within the existing performance requirements. The third cyclic process is not included in the Six Stage model because this third cyclic process also takes into account changing requirements.

Within a performance contract, the aim is to keep the asset available according to the agreed performance level and function. If the performance requirements change, the performance becomes difficult to measure and outcome uncertainty may occur. As described in the Agency theory, external factors can have an effect on these changing performance requirements. According to Trompenaars, the performance can be influenced by the dynamic environment (Trompenaars, 2007). The dynamic environment in the offshore wind industry is heavily shaped by innovation. According to Dvorak (2013) and Wraith (Wind Energy Update, 2013) wind farm owners have to compete with the newest renewable energy technologies in the wind industry.

The innovation that influences this dynamic environment, is also closely related to the critical factor of risk aversion. The agent can become increasingly risk averse if a high level of innovation needs to be required and if this occurs, it becomes expensive to pass risk to the agent, which makes a behaviour-based contract a better solution (Eisenhardt, 1989).

The level of the dynamics of innovation will be called 'innovation dynamics' and will be used in this research as the second variable to structure the future sourcing scenarios.

The 'Knowability of performance' and 'innovation dynamics' together comprises all four critical factors that are discussed in the Agency theory. At this point the focus will be on the critical transaction factors in the Transaction cost theory, which also will be included in the decision-making process to define a in-house or outsource option.

As described in paragraph 4.1, the asset specificity, uncertainty and frequency of the transaction define the most efficient boundaries of a firm (Williamson, 1985). This theory focuses on why it is sometimes beneficial to produce parts of an asset yourself and why it is sometimes more likely to outsource an activity to another organization.

Asset specificity occurs when the possible exchange requires specific investment or specific know-how to implement a certain contract (Williamson, 1985). 'Specific know-how' can also be defined as the cognitive complexity that is needed to enter into a contract. Secondly, the specific investments of the implementation of a contract are influenced by the frequency of the transaction because the frequency can lower the internal production costs by having a positive effect on the production and the enabling of administrative economies of scale, as explained in paragraph 4.1.2. These costs can be seen as the constructive complexities that may arise when a good or service is transferred across a technologically separable interface.

The constructive and cognitive complexities when transferring a good or service to another party can lead to uncertainties for the principal. Williamson explained this uncertainty as a critical transaction factor deriving from bounded rationality and opportunistic behaviour.

The cognitive and constructive complexity of the transaction can be expressed as the 'proprietary nature' of the techniques and processes that are needed to transfer or take in-house a good or service. Here the word 'proprietary nature', entails the character of the ownership of these techniques and processes from the perspective of the principal.

These techniques and processes require specific investment or know-how on the series of steps that need to be taken to achieve the particular task. The 'proprietary nature' of the needed techniques and processes of the owner for a transaction will be used in this research as the third variable to structure the future sourcing scenarios.

Because this research is focust on the perspective of the owner, only the proprietary nature through the eyes of the owner is discussed.

The variables that are relevant in the decision-making process for a new sourcing strategy for offshore wind farm O&M are the ‘knowability of the performance’ of the wind turbines, the ‘innovation dynamics’ of the industry and ‘proprietary nature’ from the perspective of the owner.

In figure 30, the link between the contract theory and the derived decision-making variables that were discussed in this paragraph are illustrated.

These three contract theory variables give an answer on the second sub-question and will be used to structure the decision-making framework in the next paragraph.

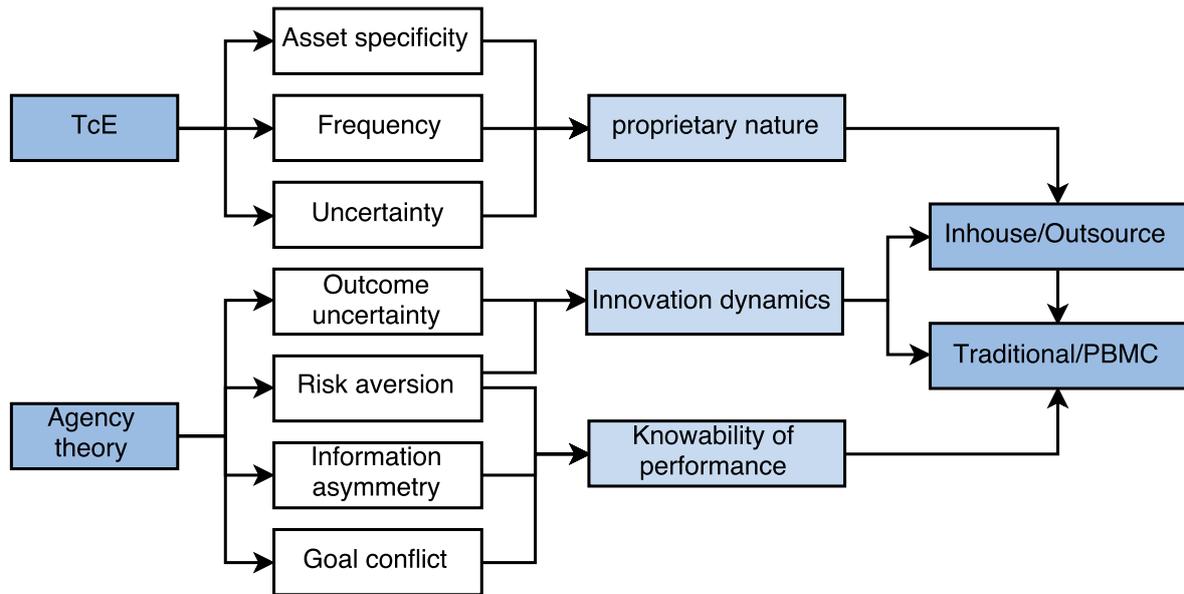


Figure (30). The relevant contract theory variables in the decision making process

Innovation dynamics

Outcome uncertainty will lead to difficulties in predicting the performance. If there is a high level of innovation and environmental dynamics, the outcome uncertainty will be higher and the time for measuring the performance will be bounded (Schoenmaker, 2011). The phases of innovation consists of the resolution of ideas to adoption, adaptation, acceptance, routinisation and infusion (Trompenaars, 2007). This takes time and often includes a lot of different perspectives. PBMC provides contractors with autonomy in their daily service operations, which in theory allows them to innovate, but this innovation is not always guaranteed (Trompenaars, 2007). Innovation also leads to uncertainty, new possible asset specific investments and the degree of utilization of asset specific transactions (frequency in transaction cost theory). The owner needs to answer the following questions in the decision-making process to define the 'Innovation dynamics' of the industry:

- What are the main innovation driven sub-components and activities?
- What is the timeframe in which the sub-component or activity need innovation? Is this within the contract period?
- Do the function requirements of the sub-components change? (political, economical, environmental, safety etc)



4.3.3 The possible sourcing scenario's

In figure 31 (a t/m i), the three decision-making variables are presented on the three axes, which shapes the three dimensional model. This model is used for the visualisation of the solution space for the post-warranty sourcing scenarios

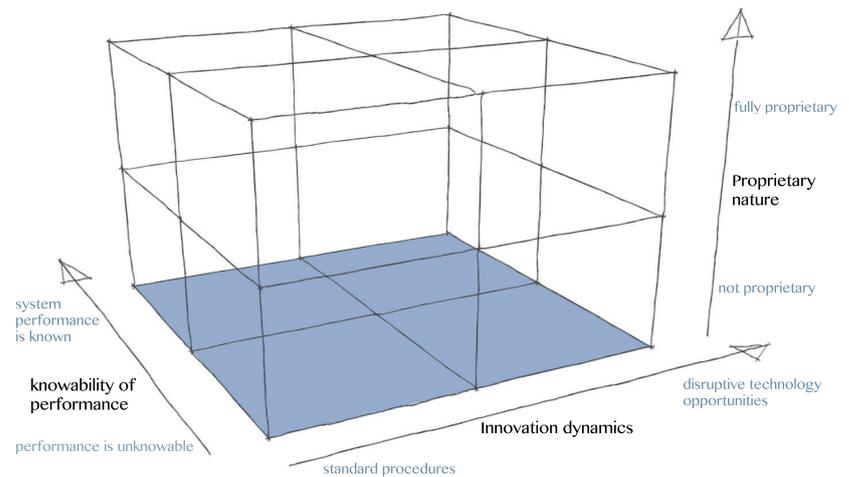
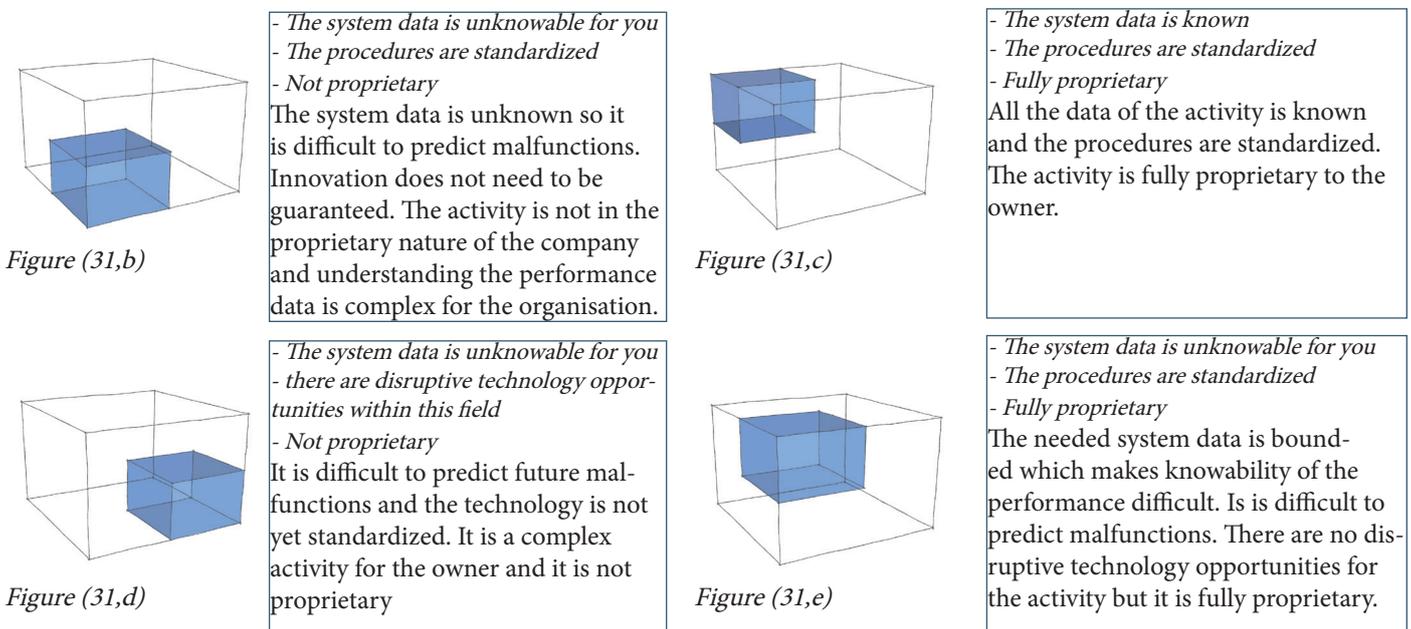
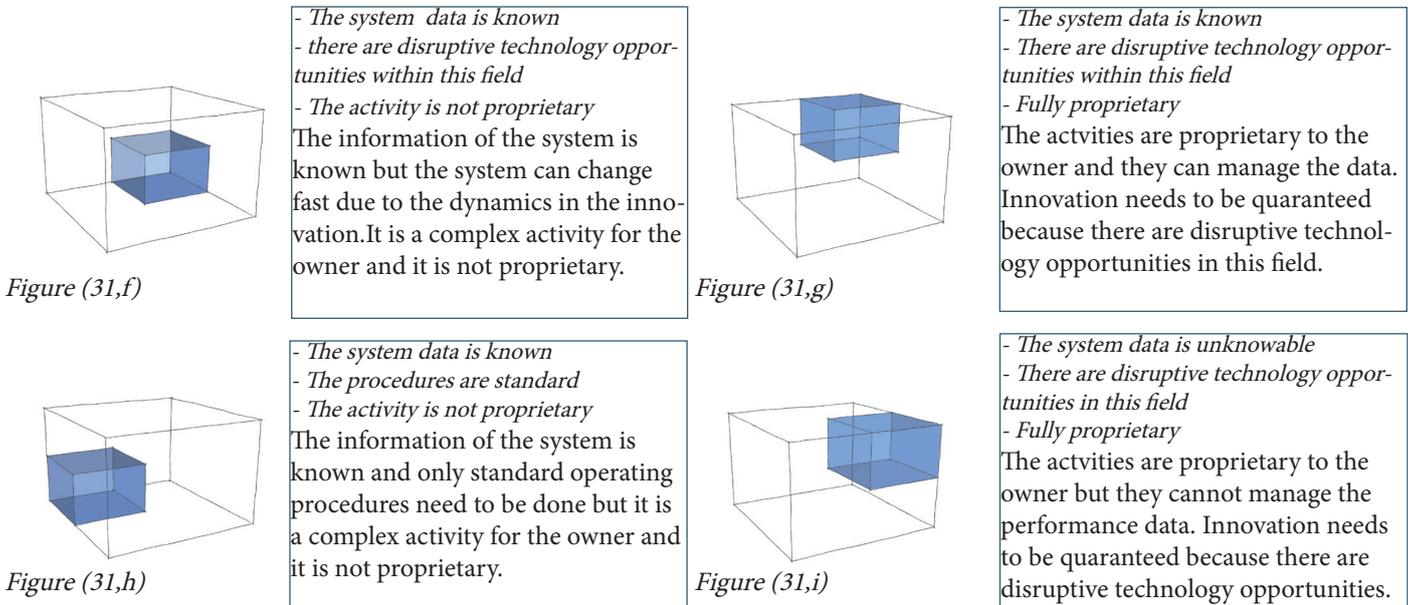


Figure (31,a). Solution space for the scenario's





The possible sourcing scenarios

All the possible combinations shown above can be summarized in four main scenarios for the owner (figure 32). The four scenarios were found by combining the boxes in figure 31b tm 31i that had the most overlapping characteristics: In figure 32 the scenarios are shown in the three dimensional model.

- o **The controller:** The data of the total system is known to the owner and the cognitive and constructive complexities are fully proprietary to the owner. The standard activities can be taken in-house but the controller can have difficulties with keeping up to date knowledge of future innovation and possibilities for these activities.
- o **The coordinator:** the cognitive and constructive complexities are fully proprietary to the owner but not all the system data regarding the performance of the turbines is known. The owner can coordinate a wide range of contractors with a centralized control structure and with the help of a behavior-based contract (traditional outsourcing). All the contractors can provide innovation in their specific field.
- o **The incubator:** The cognitive and constructive complexities regarding the transfer of the activities are not proprietary to the owner so they will not tend to take activities in-house. There are disruptive technologies in the field so specialized and dynamic companies need to bring their fresh knowledge to the incubator. If the performance of the total system can be measured and predicted, a performance-based approach with multiple service providers can be the future option.
- o **The broker:** There are no new innovations applicable for the system and due to the last degradation period, new innovations will not lead to a relatively higher output. The complexities regarding the transfer of O&M activities are not proprietary to the owner so keeping the activities with the OEM with a PBMC on availability is a future option. If the performance data is not available/not able to interpret, a behavior-based contract could be a better fit.

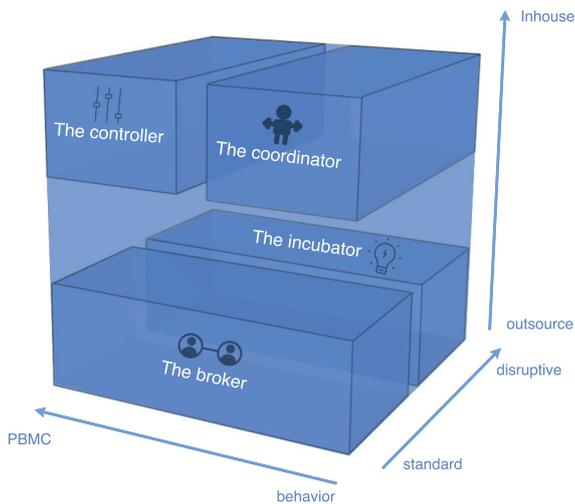


Figure (32). The four main scenarios

The scenarios further explained

In table 11 presented below, the future sourcing scenarios derived from the literature study are further explained. The table can help the owner with the identification of the outcome after working through the decision-making framework.

Scenario's	Inhouse vs outsource	Behaviour contract vs PBMC	Standard vs disruptive innovation
The broker	Outsource The O&M activities are not proprietary to the Broker. There is information asymmetry and/or a lack of asset specificity that leads to cognitive and constructive complexity for the Broker. The broker is partly rational and limited in solving complex problems and processing data, which leads to uncertainty. The outsourcing option is recommended for the Broker	The broker can still choose between a PBMC and a behaviour contract. If the performance of the total system can be measured and predicted, a performance based approach with the OEM can be the future option. But the broker has to be aware of the fact that the activity is not a core activity of its business, so information asymmetry can lead to incomplete knowledge about the performance of the asset.	Standard There is a low level of innovation dynamics that has an effect on the turbines of the Broker. There are no asset specific investment needed for new innovation and the function of the asset does not change during the contract period. The broker does not need to guarantee a high innovation level within the new contract period
The incubator	Outsource The O&M activities are not fully proprietary to the Incubator. There is information asymmetry and/or a lack of asset specificity with the OEM that leads to cognitive and constructive complexity for the Incubator. The incubator is limited in solving complex problems and processing data but can attract specialist who can.	The incubator can still choose between a few contractors with a PBMC or a bigger network of contractors (ISP's) with behaviour based contracts. The PBMC provides the contractors with autonomy in their daily service operations, which in theory allows them to innovate, that is essential for The Incubator. But the Incubator needs to be aware that this innovation is not always guaranteed and even can lead to higher uncertainty and new possible asset specific investments.	Disruptive There are disruptive technologies in the field so specialized and dynamic companies need to bring their fresh knowledge to the incubator. The incubator is limited in solving complex problems within the O&M field but can be capable of understanding the required performance of the total system.
The controller	Inhouse The Controller is capable of taking the main O&M activities inhouse because the historical data of the performance is known, the data can be interpreted and there are no extra asset specific investments needed. So, the activities are not complex for the Controller. Although the controller is capable of taking the activities inhouse, outsourcing with a PBMC is also possible because the performance of the turbines and O&M activities is known.	PBMC The desirable information of the performance of the turbines is known by the Controller. The Controller has the knowledge about the impact of possible failures, the effect of corrective and preventive maintenance interventions and about the planability of the activities.	The Controller has to operate in an environment that can either be highly innovative or can only contain standard procedures. The controller has the knowledge about the impact of possible new innovations on the turbine performance and can control possible innovation dynamics with sub-contractors.
The coordinator	Inhouse The coordinator is capable of taking the main O&M activities inhouse because the historical data of the performance is known, the data can be interpreted and there are no extra asset specific investments needed. So, the activities are not complex for the coordinator. Although the coordinator is capable of taking the activities inhouse, outsourcing multiple small execution parts with a behaviour contract is also possible.	Behaviour The activities are fully proprietary to the business of The Coordinator but not all the system data regarding the performance of the turbines is known. The owner can coordinate a wide range of contractors with the help of a behavior based contract. All the different contractors (ISP's) will plan and execute parts of the specific O&M activities.	The Coordinator has to operate in an environment that can either be highly innovative or can only contain standard procedures. The coordinator is not able to know the effect of new innovations to the turbine performance. The coordinator has to be aware that he needs to guarantee this knowledge within possible smaller behaviour contracts so information asymmetry can be minimized.

Table (11). The four main scenario's matrix

5. Composing the Decision-making Model

Experts in the field helped forming the key aspects that are the most important parts from the literature and will contribute to create a solid decision-making model. Also, the earlier mentioned Six stage Model was discussed during the interviews with the intention to find interesting input for the model.

5.1 Input from experts in the field

In the two tables presented below and on the next page, a short overview is given of the interesting insights from the interviews. Company's names or personal names are not mentioned to protect the confidentiality.

Interviewees	general	Contract
		knowability of the performance
(I-A) Windfarm owner 1	Risks will increase due to bigger windfarms, further offshore which are difficult to access. Sharing best practices will become an important factor between Owner & OEM. We help the OEM with data management, planning and sometimes even some work preparation activities (joint possibilities six stage model)	more development in CMS's to achieve a better understanding of the performance and to measure the output of the M&O activities done by the OEM with a Service & Availability contract.
(I-B) Windfarm owner 2	Back in the days, the Windfarm industry was dominated by the OEM's. Now, there is a shift happening arising where more Owners want to have more control and sometimes even take all activities inhouse. We already look for future post-warranty M&O interventions in the tender procedure in the beginning of the project. All standard day to day routine work is initiated and done by the OEM. These availability and full service contracts become too expensive for this owner due to the included risk margin. We focus on the OPEX and revenue of the farm before deciding things like knowability of performance when we make decisions	We want to know everything about asset management so that is our main focus, we want to be responsible for data management and be able to draw conclusions leading to planning and work identification. We are for example totally responsible The only problem is that intellectual property is protected by the OEM, so we do not know all details of actual work done on site.
(I-C) Original Equipment Manufacturer	There is a tendency in the market to the customer having more faith in the product. They have more operation experience so the warranty period of 5 years might be shortened. We divide our customers in two segments: - utilities who have the strong belief that they want to be operators: Short warranty period. They provide technicians themselves and have us training their technicians during this short warranty period. After the warranty period they take everything inhouse (Vattenfall & Dong) - Risk averse utilities that want security for their lenders so they want a logterm SAA (>10 y) where they pay a fixed premium. They don't have to think about anything.	Some owners are risk averse so they like long term service contracts. I think they are to some extent trying to become more operational and enabling themselves to take over if needed but it is not their base case to do so. performance data is available to them. They can access it whenever they want to. They can see all operation data, service reports, consumables, spare parts and so on. It is only whether they want to use it and/or understand it.
(I-D) Offshore contractor	There are two kinds of cost for this offshore logistic subcontractor: - cost of unavailability of fleet - M&O costs During M&O activities, the system would be unavailable which has a direct impact on the output. We work with an internal O&M department that delivers to the commerce, so all O&M is inhouse. The advantage is that a negative financial result of the O&M department can lead to positive financial results for the total company and a good system performance. All data is inhouse and there is no goal conflict. So having all asset management and offshore logistic assets inhouse can have a great advantage.	All performance data is inhouse and there is a M&O asset management department that keeps track of this data. No information asymmetry is possible and there is no room for a goal conflict.
(I-E) Public asset owner	We do PBMC's with 'kunstwerken' (bridges, locks and viaducts) The goal is to keep the asset on its functional level and it needs to meet its performance (according to the degradation line). The contractor needs to do everything according to the ISO. The performance is measured in on certain moments, so not always constantly. These sampling moments are essential when the contract is almost expired.	They first have a DBFM contract with the manufacturer and at the end of the lifetime of the asset, when the contract is expired, they do a performance measurement inspection and outsource the whole M&O with a performance contract to a new individual service contractor. So their view is: 'After the DBFM (similar to warranty period), we take everything inhouse and know enough of the performance to enter into a PBMC with a new contractor and are able to measure the performance'. They use BIM to do data management
(I-F) Asset management advisor	If you decide to enter into a performance contract, you need to do include all subsystems because it all contributes to the total performance level. The KPI's will become an important factor and will have an effect on the internal activities and outsourced components. The whole 'story' needs to be covered by these KPI's.	If you want to go to PBMC, you need to have a very good insight in your total costs of ownership, all the failure modes and the historical performance data needs to be clear. You also need to know what the effect is of M&O interventions after a failure. I think this is difficult in the windenergy sector. Information and data on the performance is essential in with PBMC's
(I-G) corporate culture & innovation theorist	If you keep control as an owner, you might miss dynamics in the market but if you outsource the activity, there is a danger that you don't have control on the activities anymore. This is what we called a dilemma and is an example of the 7th dimensions of Trompenaars: internal and external control. In the Wind Energy you can see that some companies are knowledge broking and others are innovation guarded.	There was a tendency in my research that it was the best option for windfarm owners to have strong engineers internal that controlled the most critical components but were able to control these outsourced activities because of their wide knowledge.

Table (12) General & knowability

Interviewees	Companies boundaries	External dynamics & innovation
	proprietary nature	Innovation dynamics
(I-A) Windfarm owner 1	Want to take almost all activities in-house and only ask the OEM sometimes for advice. They also use multiple ISP's as advisers for specific asset management and offshore logistic tasks. During the warranty period knowledge is already taken inhouse with the help of training procedures in cooperation with the OEM to with the goal to take the risks inhouse in the future	Innovation in data management, CMS's & marinisation of equipment
(I-B) Windfarm owner 2	Availability & Full service contract becomes expensive. They would rather work in a consortia then taking all risks. They want to be asset manager of choice to increase profit and would like to do third party management (multiple service providers and in-house control). The only problem is that there are not yet a lot of ISP's in the offshore wind in contrast to the onshore wind energy (Deutsche Windtechnik one of them).	LCoE heavily decreased due to economy of scale and more inhouse activities in stead of only full PBMC with OEM. We invest the most in CMS's and people who can work with big data.
(I-C) Original Equipment Manufacturer	Normally risk averse utility companies will choose two suppliers, a turbine supplier and a BoP supplier which takes care of on foundation, substation, cables and so on. Multicontracting is more contracting every single item individually but for this you need to have all control.	Innovation all depends on the location. One of the biggest cost drivers in operating windfarms is actually the logistics. That is because of the onshore - offshore length and the depth. Here there can be a lot of innovation, for example islands in the sea where personnel can stay and work for longer periods. Also data analytics will develop further. We have a performance diagnostic centre where we analyse all data at all times and compare them with each other (R&D data centre)
(I-D) Offshore contractor	We thought of outsourcing some specific activities on subsystems with a PBMC. The advantage was that there will be no management costs anymore and there could be more detailed knowledge incorporated. But the big problem is that potential failures in the offshore logistic field, could have an enormous impact, leading to unavailability and high costs for us. Though we sometimes can miss new knowledge and extra surveillance.	We are working a lot with CMS's systems and big data experts that can monitor all temperatures and vibrations in the vessels.

(I-E) Public asset owner	RWS has a tendency to become smaller and have a more back office role. It is a steering/guiding role because these performance contracts give a lot of room to the market to choose how to approach the M&O phase. But also the market (commercial companies) needs to adapt by not expecting specific orders from this public company. The performance contract will not include these detailed order level.	RWS wants to extract innovation from the market by introducing performance contracts
(I-F) Asset management advisor	Interesting is, 'what is the role of the owner'. Will they become more or less a broker or real M&O players who also manage the work execution of the subcontractors. This depends on the core competence of the company and their future perspective within the wind energy sector. This also depends on the innovation dynamics in the field	prediction based modelling will help the wind energy sector substantially when you want to outsource with a PBMC. You have to have data on the total life cycle which is difficult in this sector because you need to know how the degradation will develop over the years.
(I-G) corporate culture & innovation theorist	Locus of control: critical core activities are in the part in the company where internal control is dominant.	I think the clue is in the 'open innovation': How can we gain knowledge from external parties without pushing these parties away? A reconciliation of internal and external control.

Table (13). companies boundaries & innovation dynamics

Looking back on the Six Stage model and the focus on the importance of data management and planning while entering the post-warranty future, the experts in the field explained similar tendencies in the offshore wind energy industry. Innovation in data management (CMS's, big data, training etc.) needs to be controlled and understood if owners tend to take the back-office activities and maintenance operations in-house.

As the turbine manufacturer (*MHI Vestas*) confirmed, there is a tendency in the market to the customer having more faith in the wind turbines leading to owners who want to have more control. At the same time older wind turbines create a higher OPEX and a lower revenue due to degradation which can stimulate to take activities in-house instead of outsourcing on the availability.

5.2 The draft decision-making framework

The scoping decision whether to take the O&M activities in-house, include them in a PBMC or tend to choose for multiple traditional contracts can be captured with combining the sourcing strategy variables (chapter 4.3), the theoretical sourcing questions (paragraph 4.3.1) and the cost and performance drivers (literature study) in one decision making framework that is presented in figure 33.

The framework starts with the three O&M activities and their relation to the O&M costs. The three decision variables are can be identified in the framework as the three streams that start off from the beginning.

The questions derive from chapter 4.3.2 and can be answered with only a 'yes' or a 'no'. This makes it possible to run through the model in a few minutes time, giving the owner a quick overview and awareness of the possible sourcing scenario for his wind farm.

This framework was the first one drafted after the literature study and interviews with experts in the field. It was used in the first case to test the applicability and outcomes. After the first case, changes regarding the structure of the framework were made for optimisation.

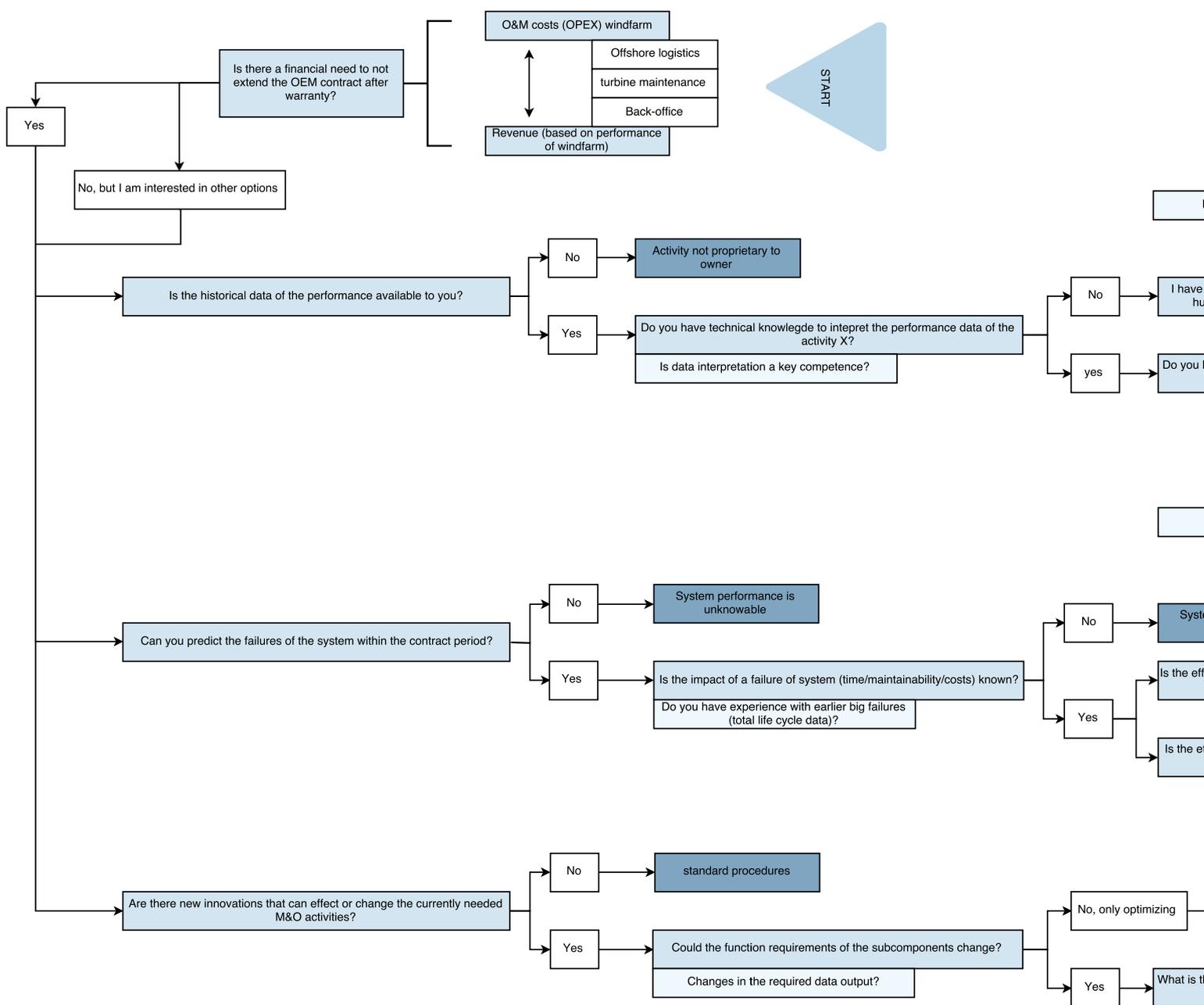
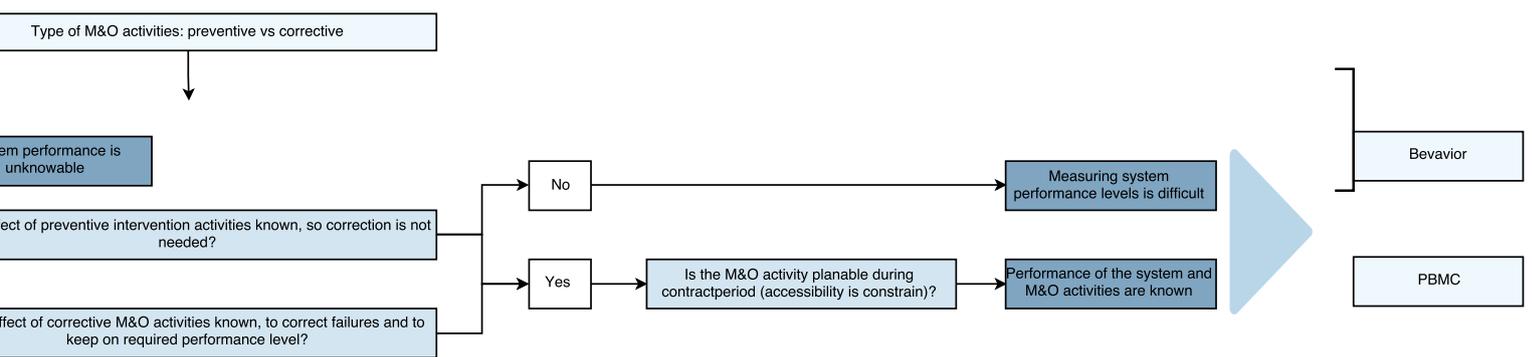
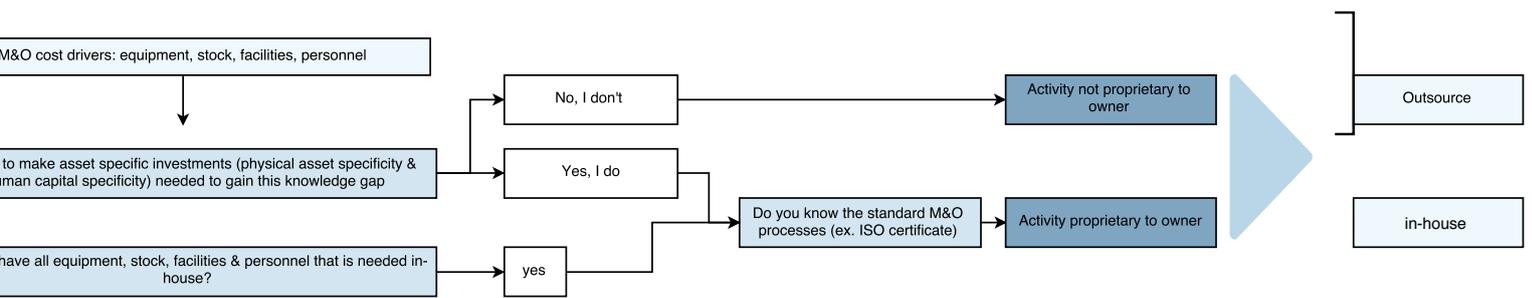


Figure (33). The decision making framework, draft



6. Case studies

In this chapter the case studies will be discussed by using the draft framework that was composed in the previous chapter. The two case studies begin with some individual case specifications followed by the application of the framework. At the end of both cases, the results deriving from the sourcing scenario figure are clarified.

6.1 The general case approach

According to Verschuren & Doorewaard (2010), this research can be described as a qualitative empirical research because a thorough literature research is done and observations are made to answer the final research question. During the case study part, the nature of the research becomes comparable with a design-oriented research method that consists of a plan to obtain certain structural solutions.

The draft decision-making framework that was composed with the knowledge of the literature study and interviews will be input for the first case. Every case will lead to new adjustments of the decision-making framework to create a constant process of improvement of the design. At the end, a solid framework based on literature and tested in real life cases, can be presented. In this way the design specifications were determined on empirical grounds (Verschuren & Doorewaard, 2010).

The output of the framework will be summarized for each case, which makes it possible to assign one of the four future scenarios (figure 32) to the owner of the wind farm. The sourcing scenarios are an indication of the possible post-warranty future sourcing option that the owner could take, based on the decision making framework and its background literature research. It is important to keep in mind that the allocation in one of the scenarios is not a path that the owner needs to take but more a likely future sourcing option.

The interesting part of the framework is that the owner can see that he or she could be capable of a certain post-warranty strategy although it is not chosen in practice. By following every single step in the framework, the owner can see which aspects define their outcome and on which aspects they need to focus if they tend to choose a different sourcing strategy.

The two wind farms that are part of the case study in this research are located in the North Sea. The two main wind farms built and operated in the North Sea off the coast of the Netherlands are included as case studies in this research because the O&M knowledge and experience of these wind farms is increased over the years. Also the first warranty periods are already expired and new future sourcing strategy decisions needed to be made. These two wind farms that are researched as case studies are called 'Wind farm Case 1' and 'Wind farm Case 2' due to confidentiality. The third wind farm is only used in the validation part of this thesis because it was operational in a later stage and therefore less comparable with the other cases. This third wind farm is still in its first warranty period but will eventually also face the same post-warranty sourcing decisions as the other cases (Netherlands Enterprise Agency, 2015 & 4cOffshore, 2017). The two wind farms in the cases have the same original equipment manufacturer but they have two different owners, which was a requirement for drawing conclusions from the case studies. The three wind farms together are marked red on the map in figure 34 (Netherlands Enterprise Agency, 2015) to show the location in relation to the Dutch coastline. These wind farms are still the main operational Dutch offshore wind farms in the North Sea. Though, during the writing of this research, the fourth Dutch offshore wind farm, Gemini Offshore Windpark, was opened on the 8th of may 2017 and is one of the largest offshore wind farms in the world with 150 turbines spanning 68 square kilometres (4cOffshore, news may 2017).

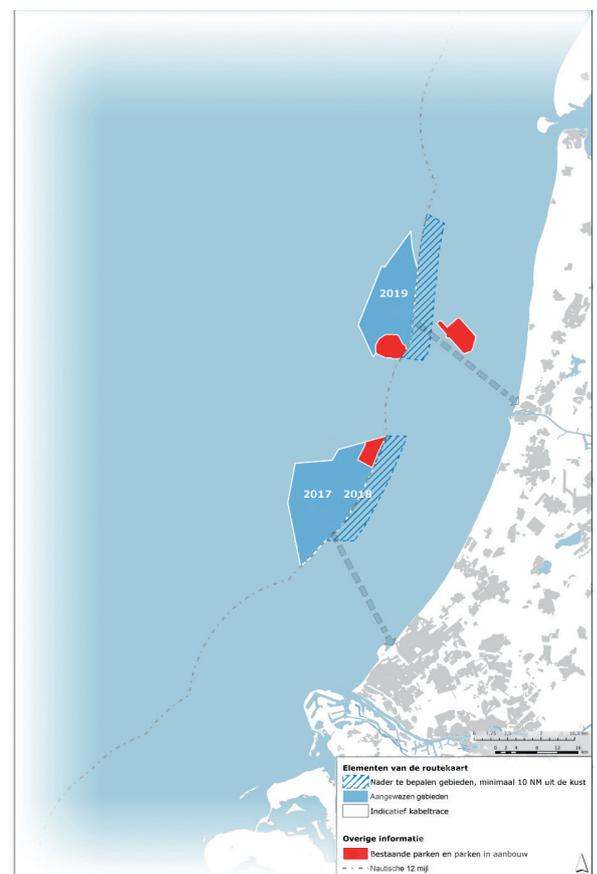


Figure (34). case studies: operational windfarms. Netherlands Enterprise Agency (2015).

6.2 Wind farm Case 1

6.2.1 Case specifications

Confidential

In this chapter the draft decision-making framework will be applied and tested on the wind farm of Case 1, to find a possible new sourcing scenario in the post-warranty future.

6.2.2 Apply the decision-making variables

The decision-making variables that define the solution space including the questions within the decision making process were discussed during the first case with the owner. Future scenarios can be drawn from these answers during the interview and put in the sourcing scenario framework (figure 32).

Proprietary nature

The historical data of the performance of the turbines is available for the owner. They use decision monitoring-systems to define abnormalities of vibrations and temperatures. They can also look into the service history of the OEM to see what O&M activities are done but they do not see on actual work execution level. They can interpret the performance data and actively monitor the failure threshold. They want to invest in asset specific investments with a sole focus on human capital specificity. More knowledge needs to be gained to analyse the O&M performance but they are willing to do so in the future. The standard O&M processes of turbine maintenance are known and they are certified on the ISO requirements.

The cognitive and constructive complexities regarding the back office activities are proprietary to the owner. This is also the case for the offshore logistics and turbine maintenance processes but this does not contain work preparation and execution. The data management on detailed operational level is not fully known because it is a core competence of the OEM, not the owner.



Knowability of the performance

The owner is able to predict failures of critical components and ask individual consultants for more advice on these predictive maintenance studies. They are heavily innovating in the impact that a failure of a critical component can have on the offshore logistics and back-office operation activities. The accessibility of the wind farms plays a very important role in combining these activities. According to the owner 70% of all the activities of the wind farm are electrical. These failures are difficult to detect but often not difficult to correct. The only big problem is that the turbines in this area are approximately 50% of the time not accessible due to the weather conditions. All in all, is the performance of the turbines not fully known to the owner and it is difficult to measure and monitor fluctuations.



Level of innovation dynamics

There are a lot of innovations in new techniques and maintenance activities of the rotor blades. These innovations do not change the data output or the function of the sub-system. They only want to innovate in O&M technologies that lower the O&M direct costs and are not innovating in increasing the availability. This is because it is easier to lower the constantly increasing O&M costs during the degradation time then invest in disruptive technologies that only drive the availability up from 95% to 96%.



'The answers in the decision-making framework are presented on the next page'

6.2.3 Case 1 wind farm through the framework

In figure 36, the answers given during the interview with the owner of Wind farm Case 1, are shown. The red coloured 'yes' or 'no' blocks present the answers of the owner. At the right hand side of the framework, the outcomes of the decision-making variables are given and also highlighted red. These answers will be the input for the recommended scenario for the wind farm owner of Wind farm Case 1 (figure 37 on the next page).

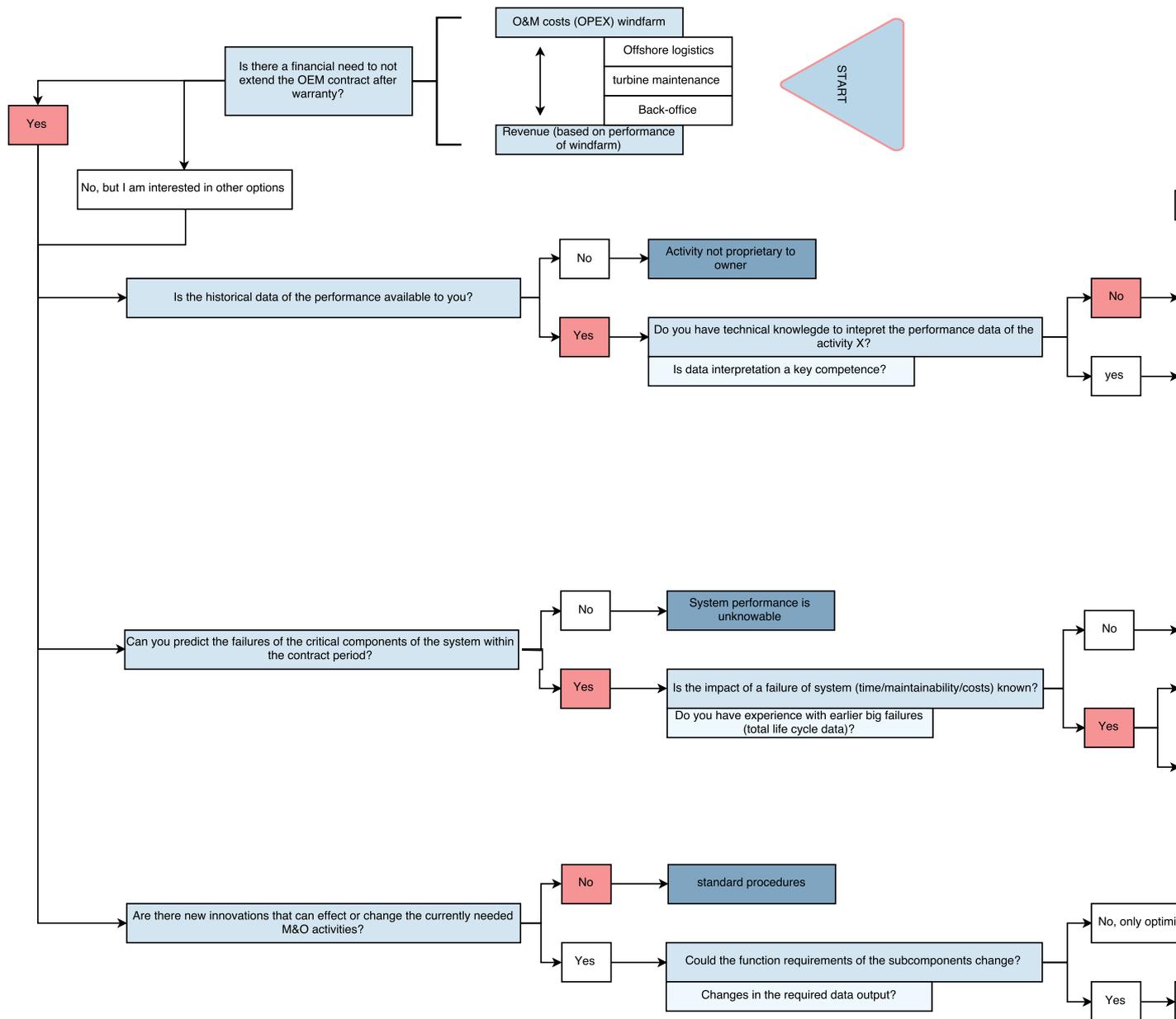
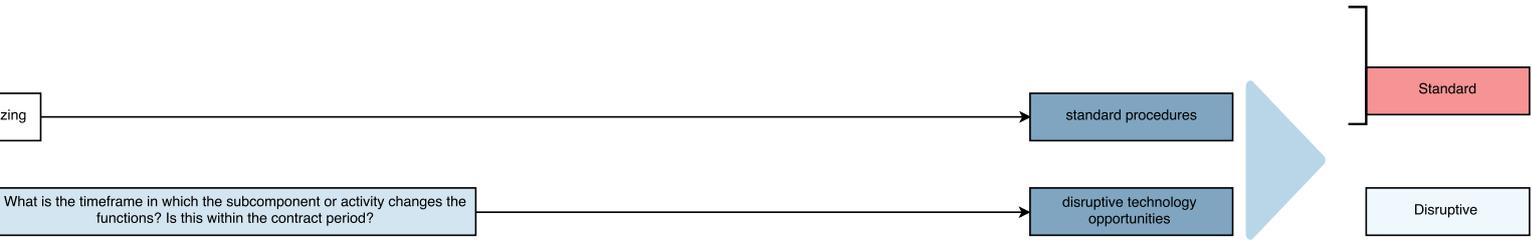
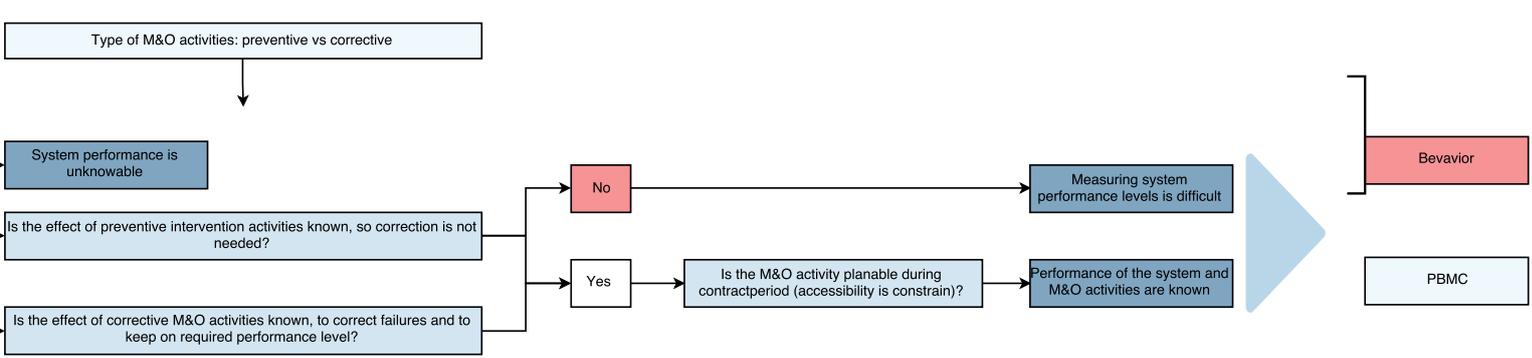
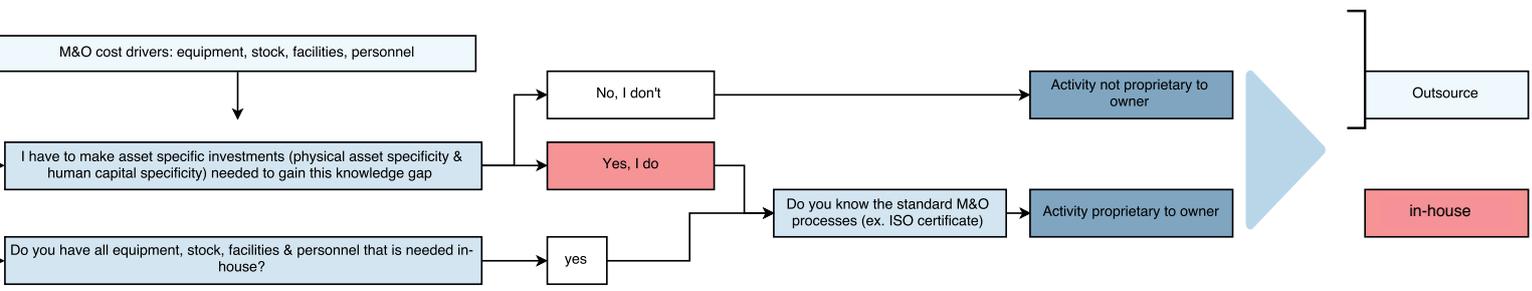


Figure (36). The decision making framework in Case 1



6.2.4 The scenario for the owner of Case 1

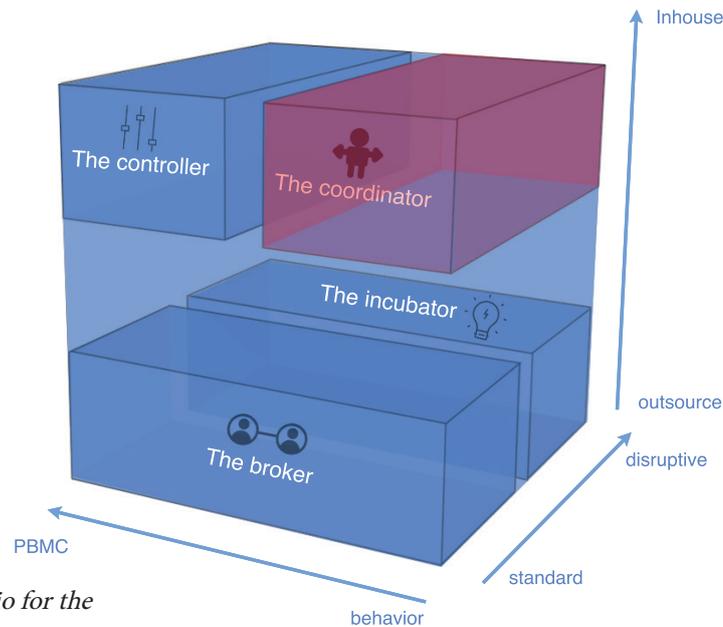


Figure (37). The recommended scenario for the owner of Wind farm Case 1

How to scope the PBMC for the post warranty future of Case 1?

The answers of the owner define the outcome of ‘The Coordinator’ scenario to scope the PBMC. The activities are fully proprietary to the owner but not all the system data regarding the performance of the turbines is known. The owner could be capable of taking the asset management and coordinating activities in-house.

According to the six stage model, this will imply that the ‘data management & planning’ can be taken in-house in the future. The owner can do all the back-office activities but has to outsource the actual turbine maintenance work execution and preparation with multiple traditional behaviour-based contracts.

The explanation of the controller scenario is again explained in the table presented below.

Scenario's	Inhouse vs outsource	Behaviour contract vs PBMC	Standard vs disruptive innovation
The coordinator	Inhouse The coordinator is capable of taking the main O&M activities inhouse because the historical data of the performance is known, the data can be interpreted and there are no extra asset specific investments needed. So, the activities are not complex for the coordinator. Although the coordinator is capable of taking the activities inhouse, outsourcing multiple small execution parts with a behaviour contract is also possible.	Behaviour The activities are fully proprietary to the business of The Coordinator but not all the system data regarding the performance of the turbines is known. The owner can coordinate a wide range of contractors with the help of a behavior based contract. All the different contractors (ISP's) will plan and execute parts of the specific O&M activities.	The Coordinator has to operate in an environment that can either be highly innovative or can only contain standard procedures. The coordinator is not able to know the effect of new innovations to the turbine performance. The coordinator has to be aware that he needs to guarantee this knowledge within possible smaller behaviour contracts so information asymmetry can be minimized.

Table (14). The controller scenario in matrix (derived from table 11)

6.2.5 Conclusions from Case 1

After the first case a few steps in the framework were still unclear for the wind farm owner.

Firstly the part where was asked about a possible financial need by comparing the revenue and the OPEX costs was not leading to a clear answer. Here the full payments of the assets were not included which gives a wrong perspective. Actually, when zooming out to the primary aim of this research and the initiative of using the framework, it can be concluded that the ‘end of warranty’ is a given fact that cannot be ignored. So, the first step of the framework has to contain the most basic question ‘Does the warranty period come to an end?’

Another conclusion of the first case is that there is not yet a clear graphical model type used, which leads to a lack of accuracy and coherence.

Also the graphical style does not yet contain a clear structure and the owner in the first case could sometimes answer a question with something different than only a ‘yes’ and a ‘no’.

When zooming in on the questions, it can be noticed that some questions lead to a more heavy weighting ‘yes’ or ‘no’ answer. It is important for the next case to make differences in killer requirements and optimization steps that lead to the final future scenario. Together with a clearer categorization and interrelation of the three streams, this will lead to a new version that can be used in the next case.

6.2.6 Adaptation of the decision-making model after the first case

In this paragraph, the conclusions of the first case will lead to adaptations in the currently composed framework.

Categorisation of the three decision-making streams

When looking closer at the three main streams that are presented in the framework used in the first case, it is possible to categorize them in three different groups. The ‘proprietary nature’ stream is focused on decision making from the perspective of the owner’s.

The proprietary nature of the complexities during a transaction for the owner will eventually define the outsource or in-house option. The ‘knowability of performance’ stream is all about the asset, which is in this case the offshore wind turbine, earlier called the OWEC system. The knowability about the asset will define the decision between the PBMC contracting option or the behavioural contract option.

The last stream is called the ‘Industry-stream’ and is about the ‘innovation dynamics’ which leads to the question whether there are disruptive technologies in the industry that may affect the future O&M activities or that there are only standard procedures needed. The ‘Owner-stream’, ‘Asset-stream’ and ‘Industry-stream’ together will be the core of the decision-making model that leads to the best possible post-warranty sourcing scenario.

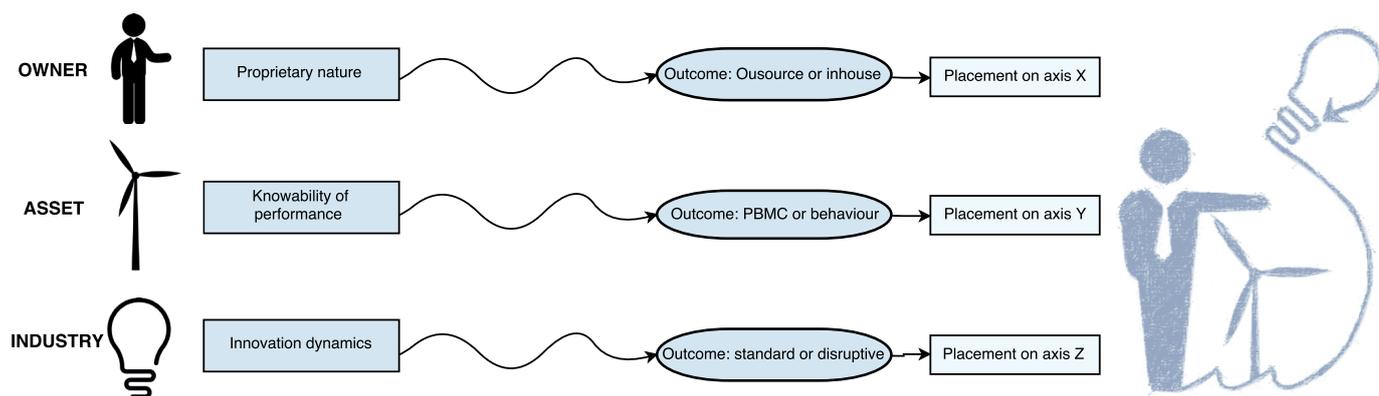


Figure (38). Catagorization of the streams

The order of the three streams is an important factor that may not be ignored. The framework starts with a focus on the owners capabilities which can be tested with the owner’s perspective on the cognitive and constructive complexity of the activities. If the core capabilities of the owner are clear, the framework zooms in on the knowability of the performance of the system.

If the activities are not complex for the owner it does not mean that the performance of the wind turbines can be known.

So, if the first stream results in an outsourcing option, the next stream will answer the question whether this outsourcing-option should be with a contract based on performance or on behaviour. If the preferred outsourcing option is known, it is necessary to look at the level of innovation dynamics of the whole industry because this has a direct effect on the outcome uncertainty and the possibilities to measure changing performance requirements (Schoenmaker, 2011).

Running through the framework in this specific order will lead to consistency and structures the variables that define the preferable sourcing scenario.

In figure 39, on the next page, the order and structure in the framework are shown. Here the black lined arrows are the direct links that combine the outcome of the previous stream with the start of the next stream. The dotted lines are the indirect links that combine previous outcomes with the next stream although the outcome does not suggest a direct link with the next stream.

This depends on whether the variables are killer requirements that exclude the other options or whether it are optimization variables that only point out a preferable option but do not exclude other possible outcome options.

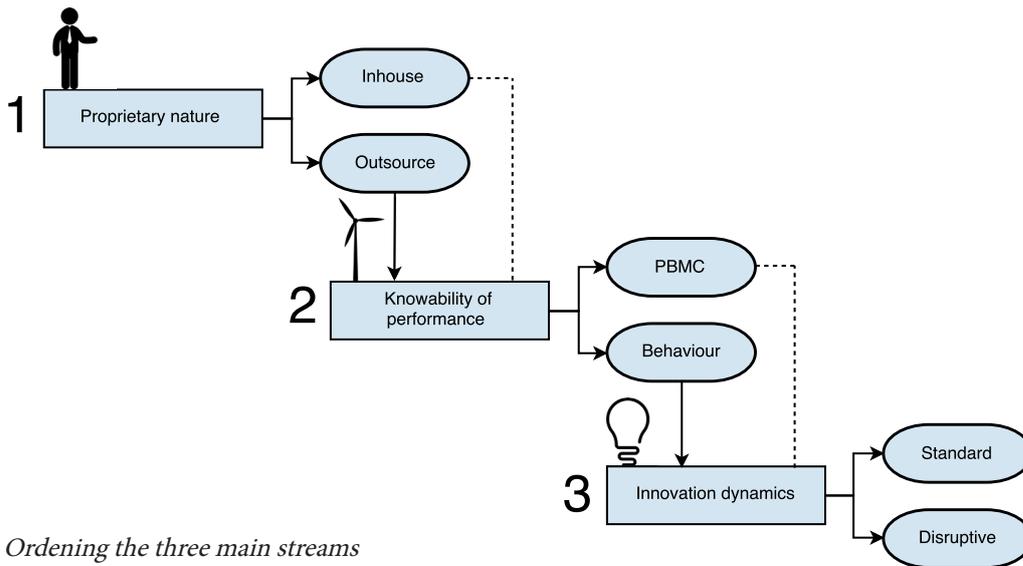


Figure (39). Ordering the three main streams

Killer requirements versus optimisation variables

During the first case, all the variables in the three streams that defined the outcomes had an equal weight. Though some variables can be seen as killer requirements that exclude other outcome options.

Some variables are optimization variables that only point out a preferable option but do not exclude other possible outcome options. The framework that was used in the first case, did not make any distinction between killer requirements and optimization variables, which is a limitation of the results in the first case.

When following all the steps of one stream it can be found that the first questions are the killer requirements that exclude one of the two outcomes and the last questions are more focussing on optimization of one of the outcomes.

At the end there are 8 possible outcomes (2 x 2 x 2) that lead to one of the four scenarios as presented in figure 32. It is very important to keep in mind that these outcomes do not lead to the best sourcing scenario for the owner but are actually an indication of a possible future sourcing scenario. After the first case, the differences between killer requirements and optimization variables were clarified in the framework.

The first two questions in each of the three streams are killer requirements. These first two questions denote a decision point in the process that leads to a certain need for the owner to choose the indicated scenario option. The next two questions in the stream denote recommended requirements. The owner is recommended to choose for the scenario outcome of this questions leads to the data output. The last question is an optimisation requirement. This question leads to the most suitable option according to the literature. It can be concluded that the output scenarios are answering the question whether owners are ‘capable’ of choosing a specific sourcing strategy.

What is the real initiative to start using the framework?

As explained in the first and second chapter of this research, the goal is to find the answer on how to scope performance-based maintenance contracts for the post-warranty O&M phase of offshore wind farms. The decision-making framework that is composed will give the owner the answer on his capabilities to follow one of the future sourcing scenarios after the warranty period has ended. So, the initiative for the owner to use the framework is the fact that the warranty period comes to an end and a new decision has to be made.

Of course there are a lot of different factors that contribute to the initiative of using the framework for a new post warranty sourcing strategy. One of the main drivers is the financial need for the owner because the operational costs of an older wind farm are high due to degradation. At the same time it is difficult to achieve a higher energy output (> 95% availability) leading to a higher performance level due to a fast degradation of the turbines in the harsh offshore environment. Other factors that could trigger the desire for a new sourcing decision in the future could for example be the influence of politics or developments in other energy industries such as in oil & gas. Though in this case, the initiative of using the framework is the expiring warranty contract.

The decision-making model type

The characteristic of decision tools is that they have to be capable of actually making or recommending decisions taking as their input empirical data (Simon, 1979). The central concern is not just with the decision outcomes but also the ways in which decisions are made. By structuring the steps that lead to a decision outcome, the owner is capable of following the steps when a decision has to be made, or reflect on critical steps when a sourcing decision is already made in the past. Here we have to keep in mind that human decision makers are as rational as their limited computational capabilities and their incomplete information permits them to be (Simon, 1979). As earlier described in the Transaction cost theory, the decision uncertainty factor derives from both the bounded rationality of the owner and the opportunistic behaviour of other parties.

There are multiple decision-making model types that are capable of recommending decisions and structure the decision-making process.

Quantitative decision-making models are based on numerical statistics and data that needs to be quantified (Monte carlo simulation, Risk-Cost analysis etc.). These models include probability distributions for uncertain events so that decision makers can weight the possible scenarios and choose the most ideal outcome. But, with the opportunistic behaviour and bounded rationality having an effect on the 'rational' decision-making, the best scenario may not exist or cannot be achieved (Simon, 1979). With the qualitative theoretical background of the transaction cost theory and agency based theory as a basis, the decision-making model will have a qualitative nature.

The sourcing strategy decision for the post-warranty period can be seen as a process with a beginning and an end. To provide a common basis of understanding of the decision-making process and to visualize the sequence of events, a decision making flowchart will be composed in this research. Flowcharts provide valuable information and insight into the specific inner workings or activities of the process (Fryman, 2001).

According to Hulbert, flowcharts, which constitute a natural language, are easily understood by managers in the industry and are useful because they graphically convey information that would be very unstructured in written form (Hulbert et al., 1972). Other benefits of a decision-making flowchart are the clarification of bottlenecks, detection of miscommunication and scoping of data input (Fryman, 2001). In comparison with other, fully rational, decision-making models, a decision flowchart will give the wind farm owner possible sourcing scenarios that he might have never considered. (Doyle & Thomason, 1999). So he might not happen to possess this new information without using the flowchart, which makes it a perfect tool for this innovative research. But these benefits of a decision-making flowchart are only realized if the flowchart is fully accurate and without un-described assumptions (Fryman, 2001). For this reason, the graphical representation needs to be consistent and follow the standard flowcharting rules.

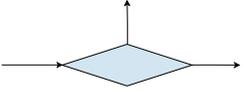
	An arrow denotes the direction, or flow, of activities in the process
	The dotted line is an indirect link to the next process steps
	The small circle is the yes or no option
	A diamond is used to denote a decision point in the process. The answer to the question is the yes option (arrow to the right) or the no option (arrow upwards)
	The ellipse represents the beginning or ending (process boundaries) of a process
	The rectangle is used to denote steps or activities in the process
	General data output or input
	Asset specific activities input

Figure (40). Flowchart symbols.

Fryman (2001) & Lucid Software Inc. (2017)

a difference between killer requirements, recommended requirements and optimization requirements. Also the initiative of using the framework is adapted and the flowchart symbols and structure are carefully applied.

Because a flowchart is a graphical representation, it is logical that specific symbols represent different types of process steps (Fryman, 2001). There are a lot of different types of flowcharts such as the system flowchart, product flowchart and, in this case, decision flowchart. Although there are multiple flowchart types, the steps and symbols are the same. In figure 40, the used symbols in this research are further explained according to Fryman's symbol types. The most basic and frequently used symbols are the ellipse (used to denote the process boundaries), the rectangle (used to denote process activities) and the diamond (used to denote decision points). Before composing the flowchart, it is important to have a clear vision on the level of detail of the total process and a well-defined beginning and end point (Fryman, 2001).

Taking into account the adaptations after the first case (described in 6.2.6), a new version of the framework is presented in figure 41 on the next full page. In this version, there is a clear categorization of the three decision-making streams and

6.3 The O&M decision-making flowchart for the offshore wind farm owner

In figure 41, the adaptations that were described in the previous paragraph have been transferred to the draft framework that was used in case 1. The adaptations of the framework include the categorisation of the decision making streams. Secondly, as the legenda shows, there is a difference between killer-, recommended-, and optimisation requirements. Thirdly, the start of the framework has changed and the characteristics of a flowchart are included in the model

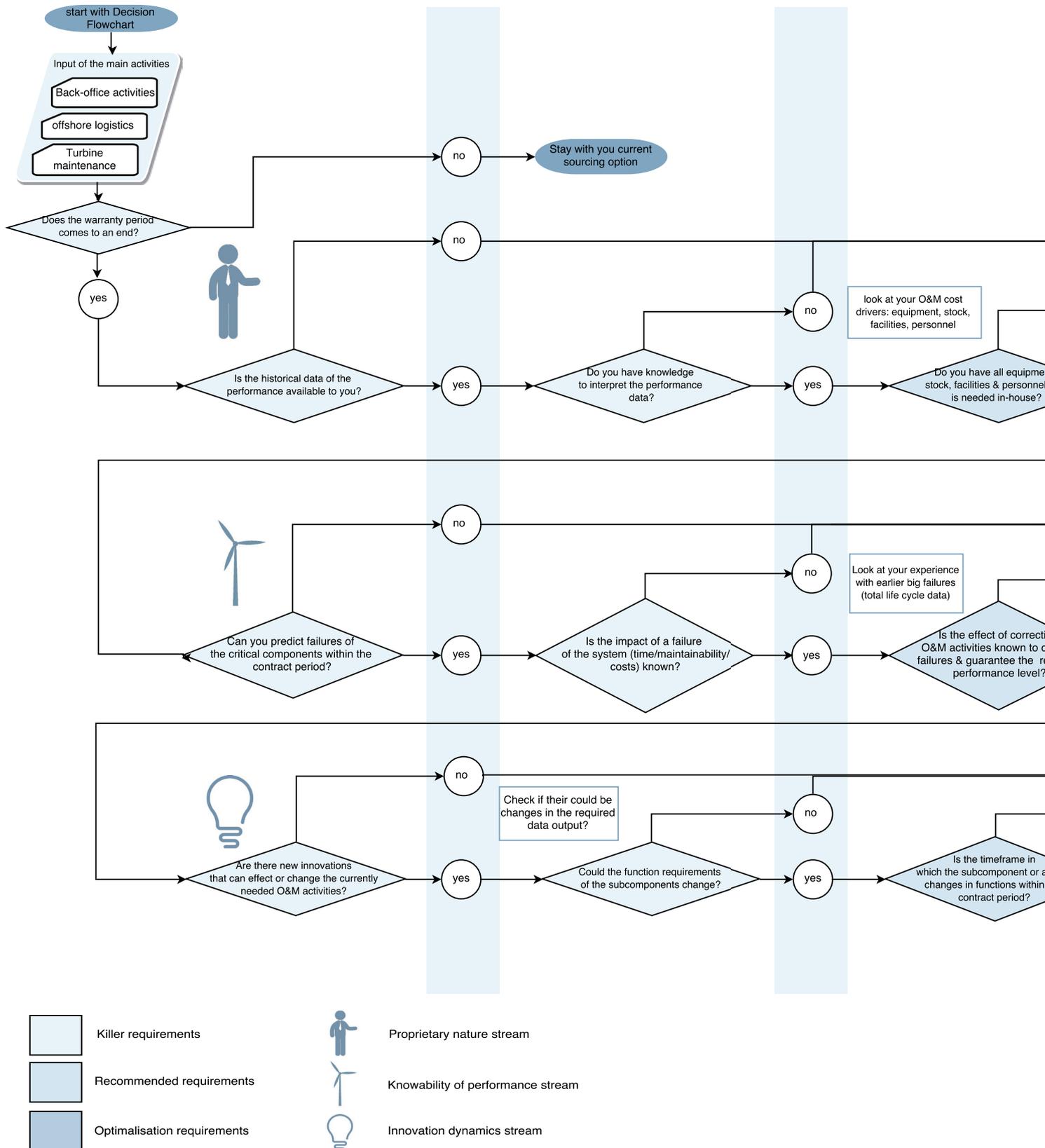
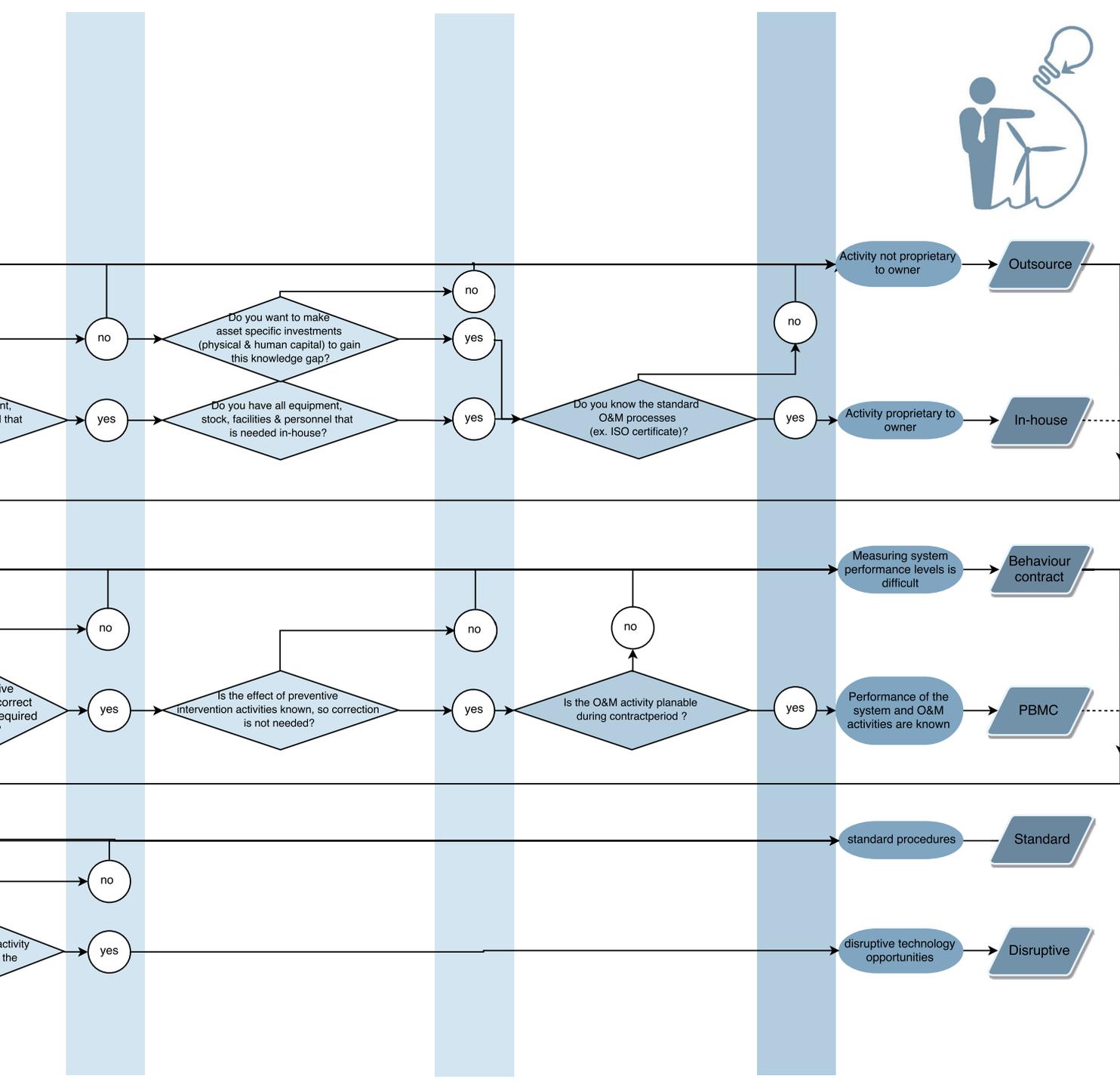


Figure (41). The decision making flowchart after the first adaptations described in 6.2.6



6.4 Wind farm Case 2

6.4.1 Case specifications

Confidential

In this chapter the newly composed decision flowchart (figure 41) will be applied and tested on the wind farm of Case 2 to find a possible new sourcing scenario in the post-warranty future.

6.4.2 Apply the decision-making variables

The decision-making variables that define the solution space including the questions within the decision making process were discussed during the second case interview. Future scenario's can be drawn from these answers during the interview and put in the sourcing scenario 3D model (figure 32).

Proprietary nature

The data that is needed for the three main activities is available. According to the owner, all the knowledge to interpret the data is in-house. They do not have all the equipment, stock and facilities in-house but they are willing to make asset specific investments in the future. At this moment new investments in human capital and physical components are already made. They also know the performance and process based maintenance steps for the turbine maintenance and asset management back-office facilities. Due to the fact that it is a demonstration project for the whole wind industry, the owner learns a lot during the warranty period about the standard O&M steps in the planning and execution phase of the turbine maintenance. It also leads to more transparency about the data during the warranty period so that they know which asset specific investments are needed to know the risks of critical component failures (high downtime, high repair costs). All these answers together lead to the conclusion that the owner is capable of performing the in-house option.



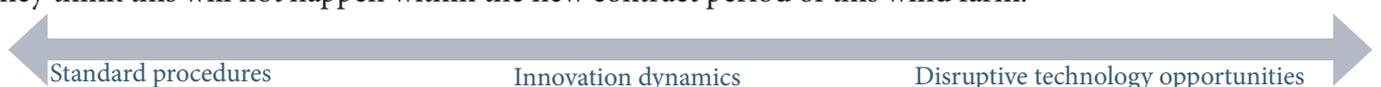
Knowability of performance

The impact of a failure of the total system is known. They can predict failures of critical components (gearbox, generator etc.) but according to the owner this depends on the amount of turbines they own. This owner only has one relatively small and older wind farm, so they can only draw conclusions from the life cycle of this wind farm. The owner wants to own more wind farms in the future, which will have a positive impact on the total amount of data that can be used for predictive maintenance. The effect of corrective maintenance is known because the staff of the owner was trained to do work planning and execution activities offshore. For the offshore logistics activities, the owner is barely capable of the effect of preventive intervention activities on the offshore logistics and the O&M turbine maintenance and offshore logistic activities are not fully planable due to the rough offshore environment. Also they do not fully know the total performance level of the offshore activities. All in all, the performance of the turbine maintenance and the back-office activities are known but not planable during the contract period. The planability is an optimization requirement and not a killer requirement so the flowchart would suggest a behaviour contract but it is not a 'must'. The offshore logistics activities already led to the 'behaviour contract' option in step three of this stream (recommended requirements). So for this activity the 'behaviour contract' option is strongly recommended according to the flowchart



Level of innovation dynamics

According to the owner there could be new innovations that can effect or change the currently needed O&M activities. Functions of the back office facilities can change due to the overall service that the owner wants to guarantee. Maybe in the future, the owner's task is not to deliver renewable energy but to guarantee renewable flexibility and the energy mix to the grid. This can lead to different performance indicators of the asset management and back office tasks. There are heavy investments in asset management and data gathering by the owner, academic institutions and the government in this subsidized pilot project. Multiple disruptive technologies such as drones and new condition measurement systems are used to gather more information. This owner also takes into account possible changes in the offshore logistics and crew transfer. In this industry there is a trend towards innovation in integral offshore logistic solutions between the offshore oil & gas plants, the offshore wind turbines, multiple offshore platforms and even the offshore fish farm industry. This leads to more effective and multifunctional networks. Although the owner is aware and expects disruptive innovations, they think this will not happen within the new contract period of this wind farm.



6.4.3 Case 2 wind farm through the flowchart

In figure 43, the answers given during the interview with the owner of Wind farm Case 2, are shown. The red coloured 'yes' or 'no' blocks present the answers of the owner. These answers will be the input for the outcome scenario for the wind farm owner of Wind farm Case 2 (figure 44 on the next page).

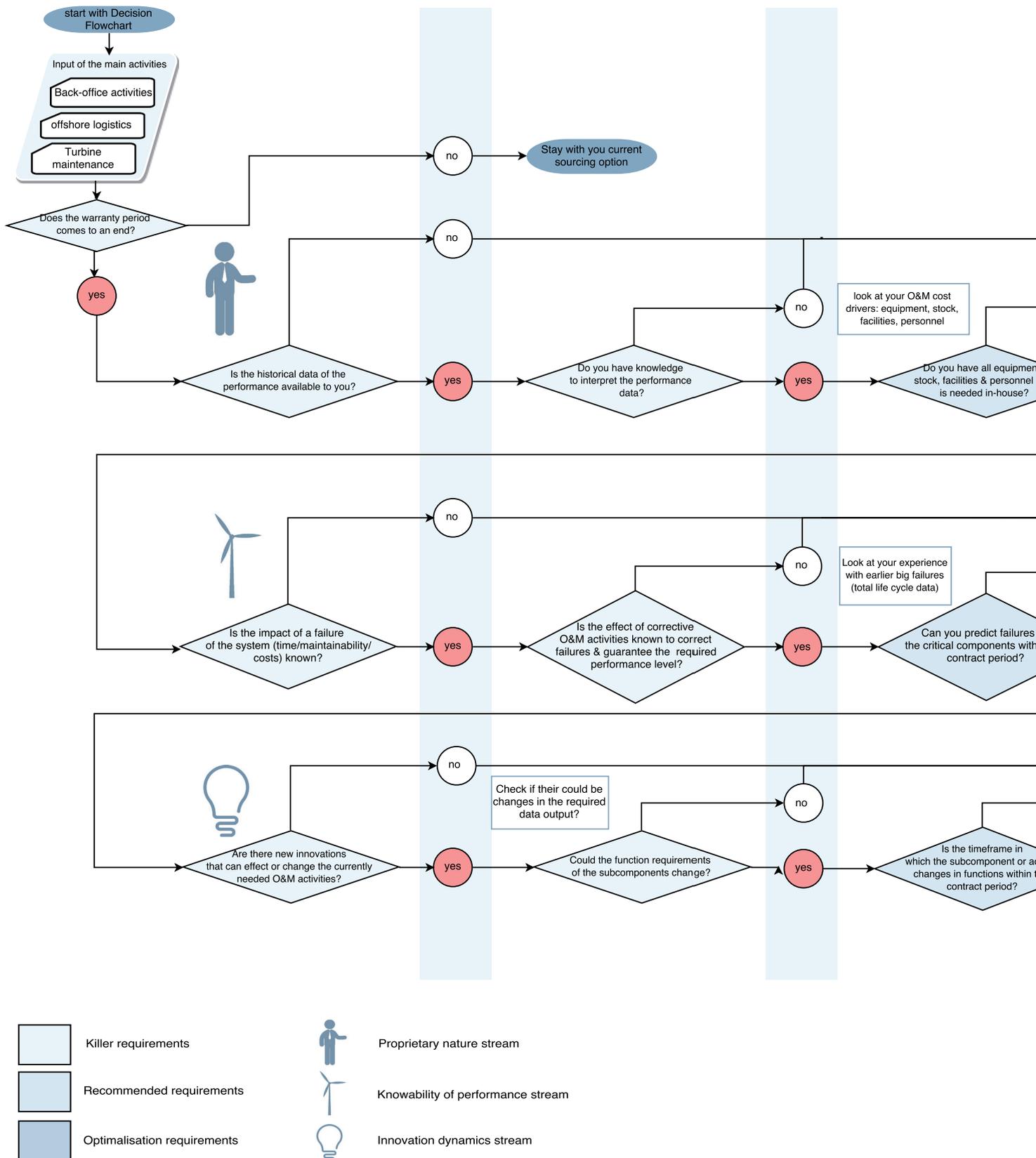
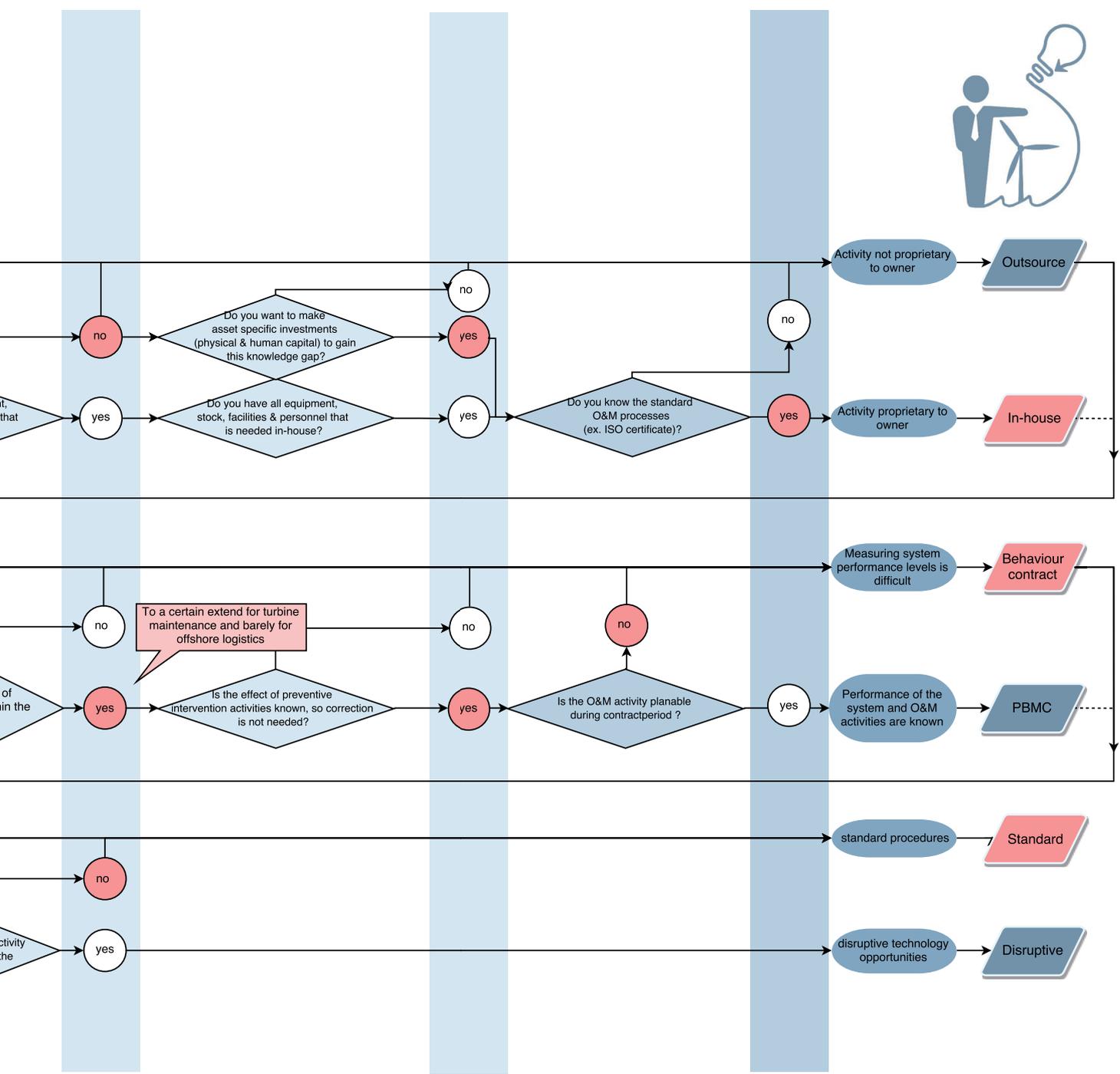


Figure (43). The decision making framework in Case 2



6.4.4 The scenario for the owner of Case 2

The owner of the wind farm in the second case, shows an outcome of ‘The Coordinator’ role in general for the three main O&M activities. But there is a difference if we look at the three activities individually. When running the offshore logistics through the decision-making flowchart, the recommending requirements led to the in-house option and the behaviour contract. When focussing on the turbine maintenance and back-office data management activities, the optimization requirements in the second stream resulted eventually in the behaviour contract, though the killer requirements did not exclude the other options in the first place. This eventually shows the tendency of the owner taking the turbine maintenance and asset management in-house but the capability to choose for an incubator role if disruptive innovation in these activities occurs within the contract period. For the offshore logistics the incubator scenario will not occur in the near future according to the owner. In figure 44 the scenario for the owner of the second case is shown and at the right-hand side the difference between the positions of the offshore logistics in comparison with the other two main activities is shown. In paragraph 6.4.6, a more detailed analysis of different hybrid scenario results is given.

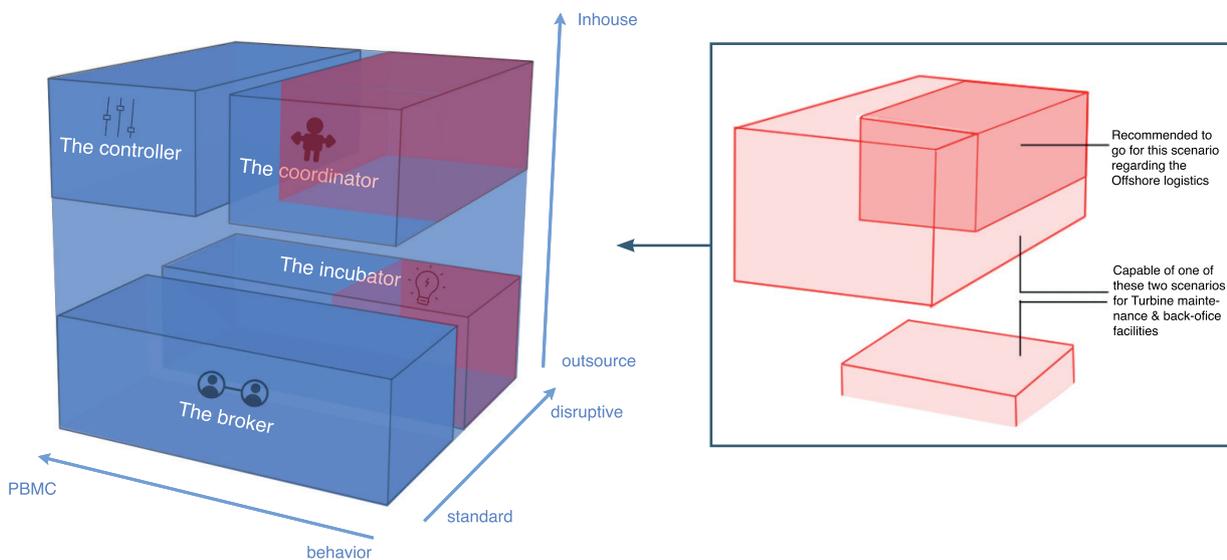


Figure (44). The recommended scenario for the owner of Case 2

How to scope the PBMC for the post warranty future of Case 2?

The owner of the wind farm in the second case, shows in general ‘The Coordinator’ scenario to scope the PBMC.

Though, this owner tends towards an Incubator approach when looking closely to developments in the turbine maintenance and data management areas. Although the Incubator role is not the most likely outcome, the owner is capable of looking from this perspective.

The complexities regarding the transaction of the activities are fully proprietary to the owner but not all the system data regarding the performance of the turbines and offshore logistics is known. The information on the performance of the major components during the warranty period is limited. The owner needs to be aware of possible information asymmetry and outcome uncertainty. The owner has already a lot of offshore knowledge regarding accessibility and downtime effects in comparison with the onshore industries.

When the owner chooses to do the turbine maintenance and back-office activities from the perspective of the Incubator, it is capable of composing a network of ISP’s with smaller behaviour-based contracts on the execution level. The owner is aware of innovative challenges in the future but does not think this will happen within the next contract period. Because this is a pilot project, they need to guarantee innovation by attracting specialized and dynamic companies

According to the Six stage model, this will imply that the owner is capable of taking the ‘data management & planning’ of the turbines in-house in the future and could look at hybrid partnerships in the work execution and analysis steps.

6.4.5 Conclusions from Case 2

In comparison with the first case, the second case showed that a lot of improvement was made regarding the smoothness of running through the flowchart and the structure in the three sequential streams. The outcome scenario was more detailed because there was the distinction between killer-, recommended-, and optimisation requirements. This creates the opportunity to end up in a scenario for one O&M activity but with a tendency towards another scenario for the other O&M activity. Here it is important to distinguish the outcome in such a way that the owner knows the difference between the scenario he is capable of, the scenario that is recommended and the killer requirements that exclude other scenarios.

During the second case, there were some difficulties in the order of the first two questions in the second stream. In 6.4.6 this will be further examined.

Another aspect that was not yet discussed in the first case is the shift in time. When using the flowchart it is a snapshot of the current situation. In the second case the owner mentioned that it is wise to run through the framework a few times a year so you can see possible shifts in scenarios. Something you are maybe capable of today could be a strong recommendation tomorrow.

6.4.6 Adaptation of the decision making model after the second case

Adaptations in the second stream 'knowability of performance'

The second stream is the 'knowability of performance' stream and consists of the requirements, derived from the literature study, that lead to the PBMC option or the behaviour-based contract. Before the second case, we first looked at the predictability of a failure of the critical components, secondly the impact of a failure of this failure and thirdly the effect of corrective O&M activities. But if total predictability is a killer requirement, it will lead instantly to the behaviour-based activity. Total predictability of failures of critical components (gearbox, rotor, generator etc) in the harsh offshore environment is not achievable at this moment. Contrary to the onshore turbines, a failure can lead to major downtime and costly corrective O&M procedures because of the limited accessibility offshore. This is why there is more innovation in preventive O&M techniques and CMS's in the offshore industry. When looking closely at the first three questions in the 'knowability of performance' stream, the following can be concluded:

- The owner needs to know the impact of a failure of the system and the effect of corrective O&M to bring the system back to the current state, if a PBMC contract is an option.
- The owner is recommended to have up to date knowledge to predict failures of critical components, if a PBMC contract could be an option.

Differences between various outcomes due to different levels of requirements

With the three different levels of requirement that were introduced after the first case, the outcome scenarios can be explained more accurately. If a killer requirement is answered with a 'no', the final scenario will be a 'need' for the owner. If a recommended requirement is answered with a 'no', the final scenario is recommended to the owner. If the final decision is made with the optimisation requirement, the owner is capable of the final scenario and is even able to look at the scenario that dropped out after the optimisation requirement. In this way the owner can understand his options and current position in a more precisely.

In figure 45, the different levels of scenario outcomes are shown. The light blue area contains the scenario that the owner is capable of including the options in other scenarios.

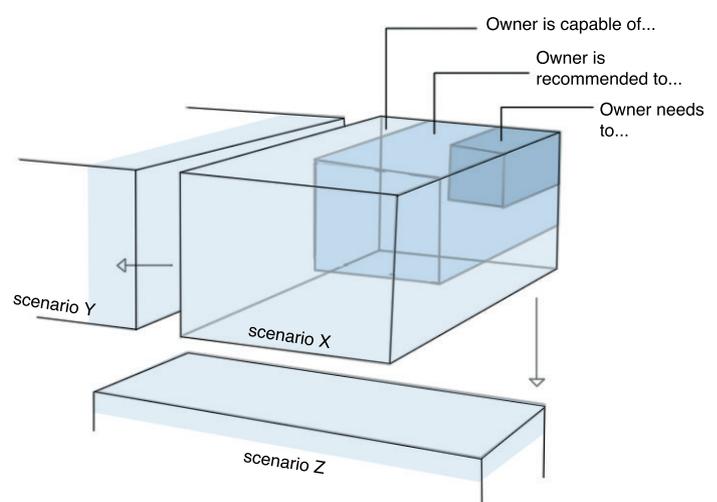


Figure (45). The different levels of scenario outcomes

Working the other way around

After the second case, the scenario for the wind farm owner was derived from the flowchart.

The owner normally starts at the beginning and work through the question-steps till the end. During the interview, the wind farm owner raised the question wether it is possible to work through the flowchart the other way around, starting at the end. When working on Case 2 it was found that it was indeed possible to first look at the outcome scenarios and from there start with the end of the flowchart.

If the owner can identify himself with one of the scenarios but is willing to consider one of the other scenarios, he is able to look back at the requirements to find a bottleneck that defines the current situation. This could be helpful if decisions are already made in the past and the owner wants to look back on the structure of the sourcing process.

For example, in figure 46, a simplified flowchart of an owner in the Incubator scenario is shown. The owner did never use the flowchart but he can identify himself with The Incubator scenario by reading the explanation of the four scenarios (table 11). By using the flowchart he can look back on the sourcing decision-making process from The Incubator position and identify the bottlenecks (red dots in figure 46) that led to his current scenario. So, he knows which bottlenecks he has to tackle if there is a desire to follow another scenario in the future. So the wind farm owners can use the decision-making flowchart in three different points in time. Firstly, they can use the flowchart before the decision-making process to get a feeling and indication of what is coming and which scenarios are possible. Secondly, they can use it while they are in the middle of the decision-making process to structure the steps. Thirdly, they can use it even after the decision making process to work the other way around and find the bottlenecks that could have defined the current scenario.

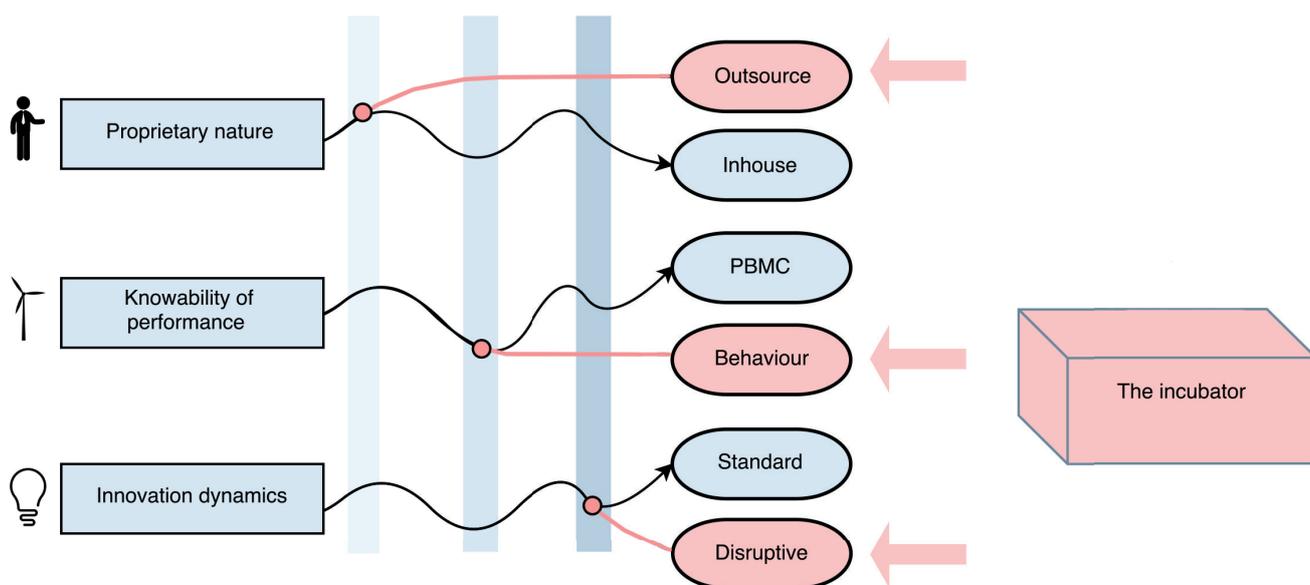


Figure (46). Working the other way around

7. The final decision-making flowchart

7.1 Reflection on the cases

The first wind farm owner worked with the draft flowchart and ended up in The Coordinator scenario. When working for the first time with the draft flowchart on a real life case, it became clear that a few specific adaptations were needed. After the first case there was a moment of reflection on the primary initiative of using the flowchart, which led to the realisation that the real driver is the expiring of a warranty contract.

Another conclusion of the first case is that there was a lack of accuracy and coherence. With the help of one structured flowchart model type it became more comprehensible.

Next, the categorisation and interrelation of the three decision-making streams contributed to the direct link between the background contract theory and the usage of the flowchart. Together with the upgrade of three different requirement levels (killer-, recommended - and optimisation-), the adaptations after case one created a more solid and effective tool.

The applicability of the flowchart so far was tested again in the second case.

The owner of the wind farm in the second case also ended up in the 'The Coordinator' scenario to scope the PBMC, but this owner tended towards an Incubator approach when looking closely to developments in the turbine maintenance and data management areas. This shift was identified because the flowchart now gave the option to derive different scenarios for the different main O&M input activities. Also different requirement levels gave the flowchart the option to show the owner different weights of the outcome. This is an important improvement because if the owner is capable of a scenario it does not mean that this scenario is recommended or needed. In the second case the Incubator scenario for the turbine maintenance and back-office activities is not the most likely outcome, but the owner is capable of looking from this perspective so he could consider a new sourcing strategy in the future. If the owner can identify himself with one of the scenarios but is willing to consider one of the other scenario's, he is also able to look back at the requirements to find a bottleneck that defines the current situation.

After the cases, the following side notes need to be mentioned to understand and interpret the flowchart and its outcomes:

Firstly, The answer in the first case is static in comparison with the more hybrid scenario in the second case. This is because the first case did not show differences between the answers of the three activities and the second case did. The adaptations created these hybrid outcomes, so the design oriented structure of this research contributed to a more specific outcome in the second case in comparison to the first case. Still, it needs to be mentioned that the outcomes can be biased due to the interview skills of the researcher and the ability of giving clear answers by the wind farm owner. This can lead to more specific answers in one case in comparison with another case and may have effected the more hybrid scenario in case 2.

Secondly, it is important to understand that the two terms on both sides of the axis (in-house-outsourcing, PBMC-behaviour, standard-disruptive) are not two opposite extremes of the stream. Actually the three streams can be seen as dimensions that all have two different outcome orientation points. These two outcome orientation points have totally different requirements and characteristics as shown in the transaction cost theory and agency theory. But be aware that there is no difference between right or wrong and there is no ultimate outcome.

The owner has to be careful to not show opportunistic behaviour while working with the flowchart if he wants to ensure a realistic outcome.

Thirdly, during the cases, all the three O&M activities needed to go through the flowchart individually to find out which sourcing scenario suited. Going through all the steps three times can lead to a chaotic way of interviewing and a misunderstanding between the researcher and the wind farm owner can easily happen.

All in all, chapter 6 answered the third sub-question empirically during the cases.

The decision-making options within a performance-based contract for post-warranty O&M of offshore wind farms are all captured in the flowchart that is composed and tested in the cases. The decision-making options

all-together lead to the final four scenario's that can be a possible future sourcing strategy scenario after the warranty period.

After interviewing experts in the field and discussing the cases, the applicability of the three contract variables in practice were tested. In table 15 presented below, the four scenarios are shown in relation to the three streams and the contract theory variables that where examined in chapter 4. With this figure, the owner can be able to easily get an overview of the consequences of his scenario in relation to the contract theories. This can create awareness of the consequences for the owner when he finally chooses for one of the four scenarios.

Decision making streams	contract theory variables	The Broker	The Incubator	The coordinator	The controller
 Proprietary nature	Asset specificity	low	Low	high	high
	Uncertainty	high	high	low	low
	Frequency	low	low	high	high
 Knowability of performance	Information assymetry	medium	medium	high	low
	Goal conflict	medium	high	low	high
	Risk aversion	high	medium	high	low
 Innovation dynamics	Outcome uncertainty	low	high	high	low

Table (15). The scenarios linked back to the contract theory

In the decision-making flowchart (chapter 6.5) it can be seen how the sourcing strategy scenarios influence the decision-making variables by working the other way around, as explained in figure 46. Following one of the scenarios in the sourcing process can directly be linked to the contract theory background from chapter 4. In table 15 the 4 scenarios are again linked to the contract theory background. This table can be used by the owner of the wind farm for identifying consequences of a possible scenario. For example, if the Owner has The Coordinator scenario for the post warranty future, he has to be careful of the high-risk aversion and high outcome uncertainty. Though The Coordinator has a high asset specificity and low goal conflict. The owner has to be aware of both these negative and positive sides of the scenarios.

Working the other way around with the flowchart and using table 11 and 15, gives the direct answer to the last sub-question, regarding the influence of the sourcing scenarios on the decision-making variables. This influence is important for the owner because it gives a clear understanding of the consequences of choosing one of the four sourcing scenario's and creates awareness of possible pitfalls.

7.2 Reflection on the four scenarios

Capturing the four scenarios in a graphical 3D picture with three axes shaped a rigid figure of the real situation. In this paragraph a reflection on the four scenarios will discuss whether these scenarios show flexibilities that are not shown in the 3D sourcing solutions figure. To define these flexibilities, it will be discussed whether the scenarios show mutually exclusive and collectively exhaustive characteristics. Two scenarios are mutually exclusive when they cannot both occur whereas two scenarios are collectively exhaustive if at least one of the scenarios must occur and their union covers all the possible scenarios. If the 3D model is both mutually exclusive and collectively exhaustive, it is called MECE (Kazancioglu et al., 2005). For a thorough understanding of the possible scenario outcomes, it is important to discuss the degree to which the spatial boundaries between the scenarios are pliable in reality. In the second sub-paragraph, the dimension of time will be discussed, to found out if the model is also flexible over time.

7.2.1 The flexibility between the four sourcing scenarios

The sourcing scenario model in this research is not a visual representation that displays what is already known, but is a visual model that supports the creative and innovative task of discovering and structuring possible sourcing scenarios in the future. In this paragraph possible flexibility in the initial rigid sourcing scenario model (figure 32) will be discussed and explained.

The Controller

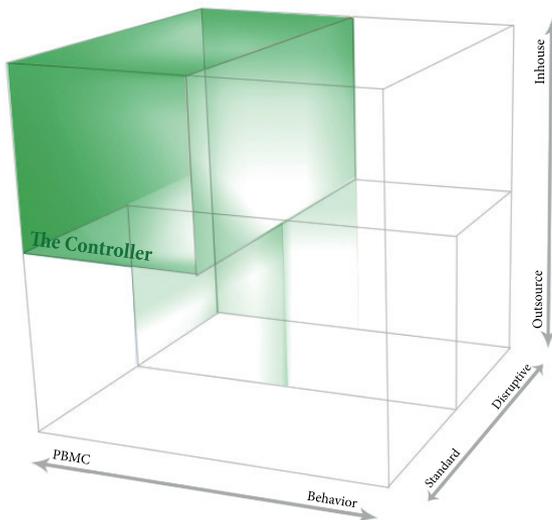


Figure (47,a). The Controller reflection

The Controller is capable of taking the O&M activities in-house because it is their proprietary nature. Although the controller is capable of the in-house solution, outsourcing with a PBMC contract is also possible because there is enough knowledge on the performance output. The controller has to operate in an environment that can either be highly innovative or can only contain standard procedures. The outsourcing option could be preferred by the Controller when a rapid technological innovation level is expected in the next contract period. The Controller has the knowledge of the impact of new innovations on the turbine performance and is able to control a few contractors with a contract based on these performances. The controller will not run into a behaviour based contract because this can lead to a high goal conflict while the Controller, as the name implies, wants to have control over the final outcome. The green area in figure 47a covers the same box as illustrated in figure 32, but also shows the capability of the outsourcing option when the innovation level is high.

The Coordinator

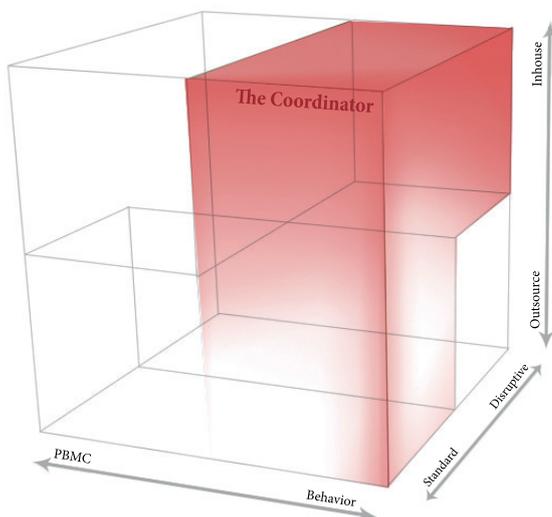


Figure (47,b). The Coordinator reflection

Like the Controller, the Coordinator is also capable of taking the main O&M activities in-house. Although the Coordinator is capable of taking the activities in-house, outsourcing with multiple small execution parts with behaviour-based contracts is also possible. This outsourcing option could be preferred when there are no disruptive innovations because if the activities are standard procedures, the Coordinator is able to coordinate the separate different behavior contracts.

The Coordinator has a higher information asymmetry, higher risk aversion and a lower goal conflict in comparison with the Controller. As the name implies, the Coordinator is able to coordinate multiple contractors on their behaviour.

The red area in 47b covers the same box as illustrated in figure 32, but also shows the capability of the outsourcing option when there are standard procedures.

The Broker

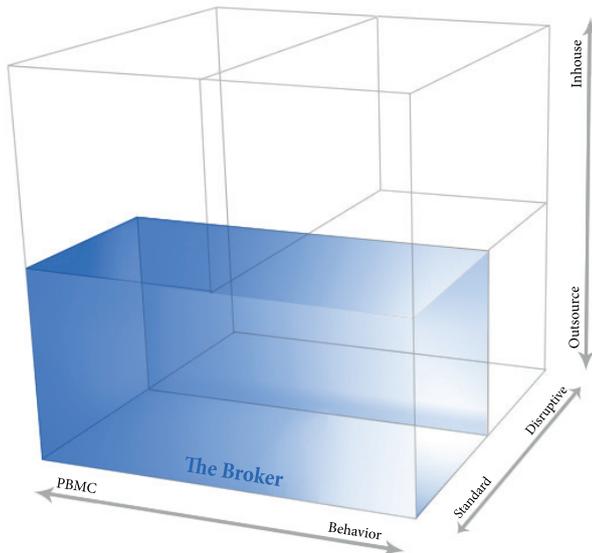


Figure (47c). The Broker reflection

The Broker has a low frequency of transaction and a low asset specificity. Also high information asymmetry and/or a lack of asset specificity lead to cognitive and constructive complexity for the Broker. The outsourcing option is needed for the Broker. There is high uncertainty because the Broker is partly rational and limited in processing the available data in practise. The function of the Broker's assets do not change fast due to innovation during the contract period. The blue area of the Broker in figure 47c is more focused on the PBMC contract because as the name 'Broker' implies, the owner outsources all the O&M activities based on the final performance of the wind farm and brings together all the needed contractors to achieve the final goal. The Broker has to be aware of the fact that the activities are not part of the core business, so information asymmetry can lead to incomplete knowledge and risk aversion. This is why figure 47c mainly covers the performance-based area (dark blue). The broker is not able to cover other parts of the sourcing 3D model.

The Incubator

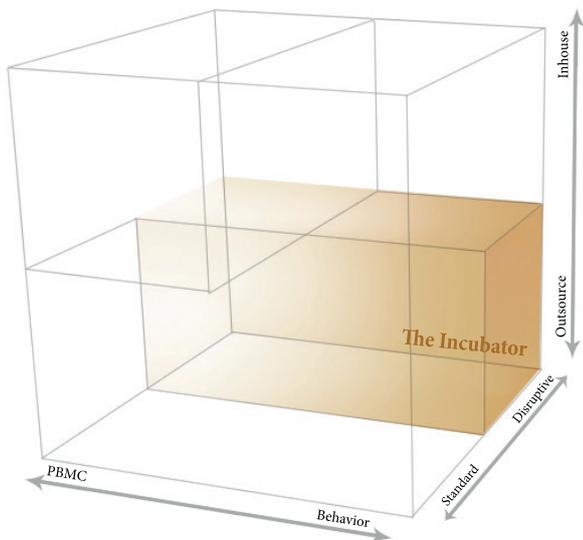


Figure (47d). The Incubator reflection

The incubator is limited in solving complex problems and processing data but can attract specialists who can. There are disruptive technologies in the scenario of the incubator and dynamic companies need to bring fresh knowledge to the owner. The incubator is both capable of outsourcing with a PBMC or with a behaviour based contract. The PBMC provides the contractors with autonomy in their daily service operations activities, which in theory allows them to innovate if they want to cut costs.

With a behaviour contract the Incubator is able to steer innovative solutions themselves. This is why figure 47d mainly covers the 'behaviour contract area' (darker area). Though keep in mind that the PBMC option is still considerable for the Incubator when the outcome uncertainty is high and a goal conflict lies in wait. The broker is not able to cover other parts of the sourcing 3D model.

If the four sourcing scenarios are mutually exclusive and collectively exhaustive, it could be called a MECE. In the Coordinator & Controller scenario a flexibility of the boundary between the outsourcing option and the in-house option is observed. The Controller scenario can have an overlap with the Incubator scenario if the Controller chooses for outsourcing. This is possible when there is enough knowledge of the impact of new innovations on the turbine performance and when the owner is able to control contractors with a behaviour-based contract.

Another flexibility between scenarios is the Coordinator scenario that can move downwards to the outsourcing side with a behaviour-based contracts when the activities are standardized. So, the 3D model with the four sourcing scenarios cannot be a MECE because the scenarios can have an overlapping part, which means that they are not mutually exclusive. Though, the four scenarios together cover all possibilities within this sourcing model, which makes them collectively exhaustive. This means that at least one scenario must occur in the future.

It can be concluded that the observed flexibility in both cases is caused by the boundary between the in-house option and outsourcing option. Only this spatial boundary is pliable in this sourcing model because the

Coordinator and The Controller are in their nature owners who would prefer the in-house option but they are capable of a outsource solution if the innovation dynamics gives them the chance.

It can also be concluded that the Broker and the Incubator cannot shift to the in-house option and are also not able to overlap each other. These two scenarios are limited to the boxes that were defined in figure 32 and are more represented in one corner of the box.

In figure 48 the four sourcing scenarios and their boundaries are shown. The darker planes with the solid black lines are boundaries that show mutually exclusive relations.

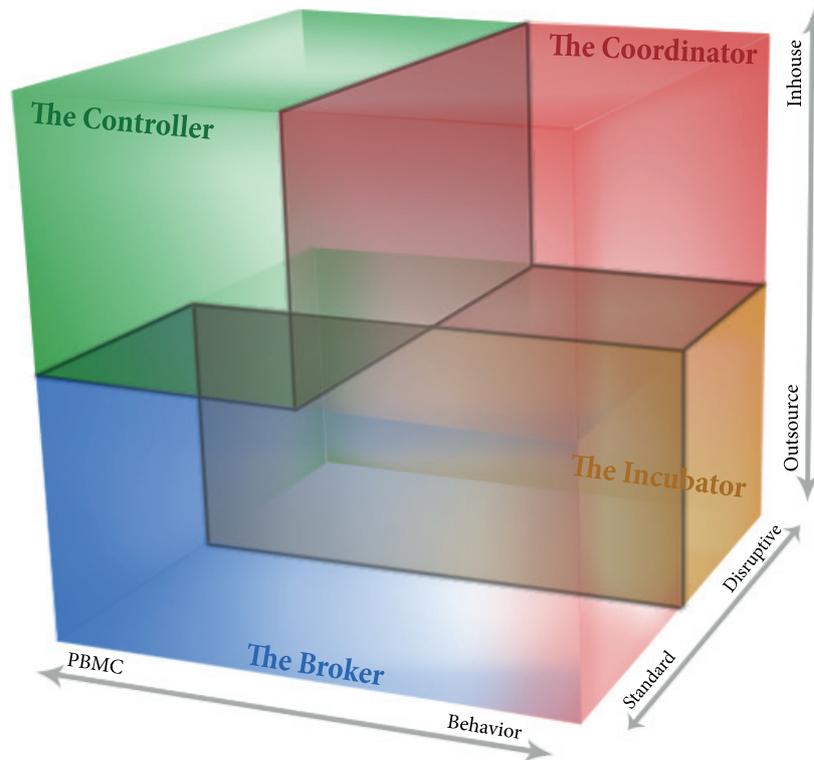


Figure (48). The sourcing scenario boundaries

7.2.2 The four scenarios over time

Running through the decision flowchart can be done at different points in time, which means that the scenario outcomes of the case studies are a representation of a needed, recommended or possible sourcing scenario at a chosen point in time. The decision flowchart can be used before, after or during the post-warranty decision making period. The time of using the decision flowchart will depend on the goal you want to achieve. Using the decision framework before you enter into a contract will make the owner aware of the different scenario options and can influence the future sourcing process. Secondly, using the decision framework during the post-warranty contract can help the owner with organizing the decision process. Last but not least, using the decision flowchart after a post-warranty O&M contract is already signed can help the owner during the feedback and analysing process. The owner will be able to identify the current scenario and can use the model to learn from the previous decision process.

It is important to emphasize that the sourcing flowchart presented in this thesis, does not take into account different decisions over time. Though, the flowchart can be used at an arbitrary point in time to get an overview of the outcome in the current situation.

So, the overlapping parts in the sourcing outcome model are a flexibility of the spatial boundaries and not flexibilities over time.

7.3 Result of the final decision-making flowchart

Model description

The final decision-making flowchart is the result after the adaptations of the theoretical draft flowchart during the case studies. The flowchart is composed through the eyes of the wind farm owner.

The initiative of using the flowchart is the expiring of the current warranty contract with the OEM. If the warranty period is ending, the owner can work through the flowchart by beginning to focus on his cognitive and constructive complexities to define the ability to take the O&M activities in-house. After defining the outsource or in-house option, the owner needs to look at the performance of the asset in relation to the O&M

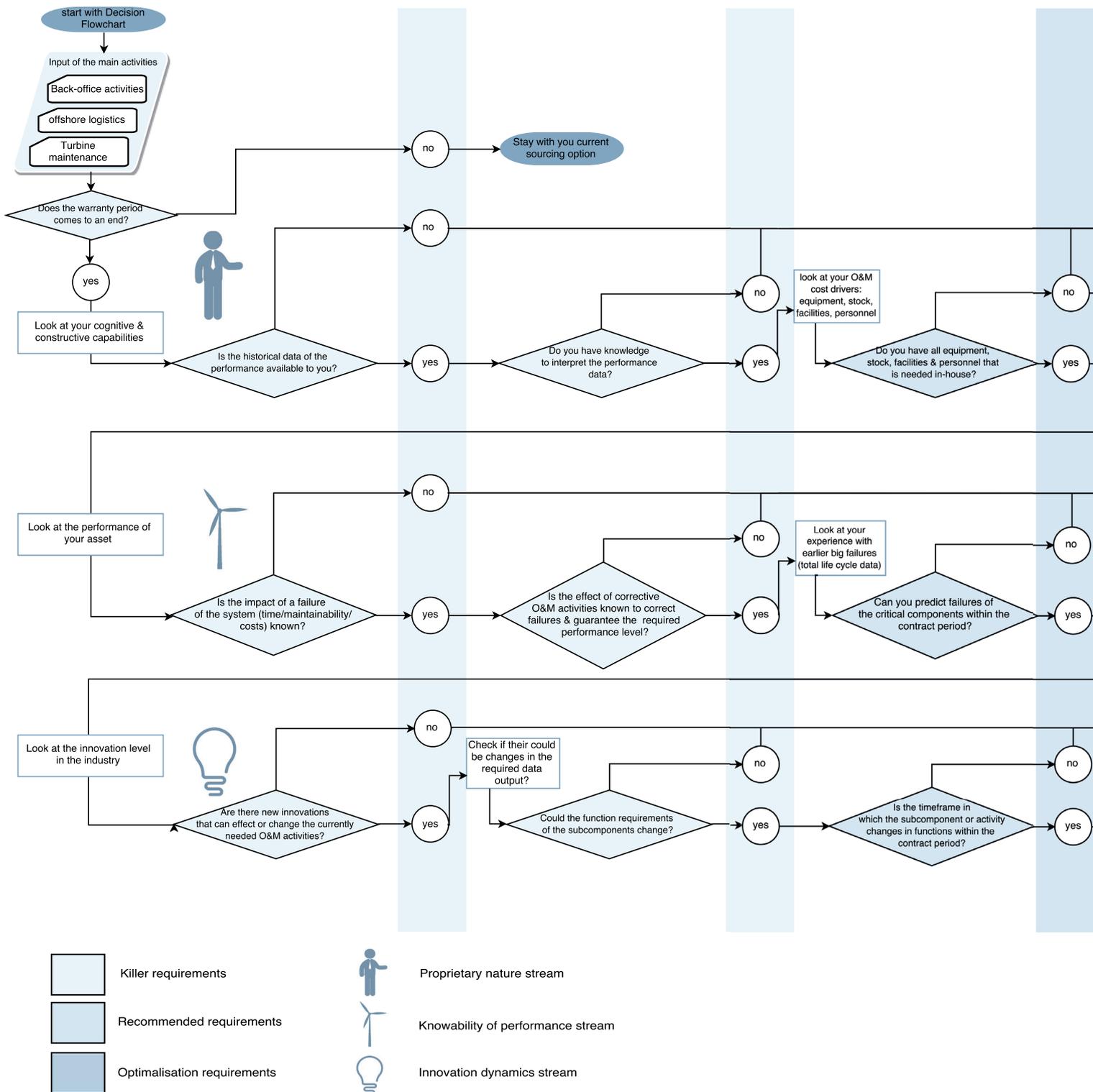
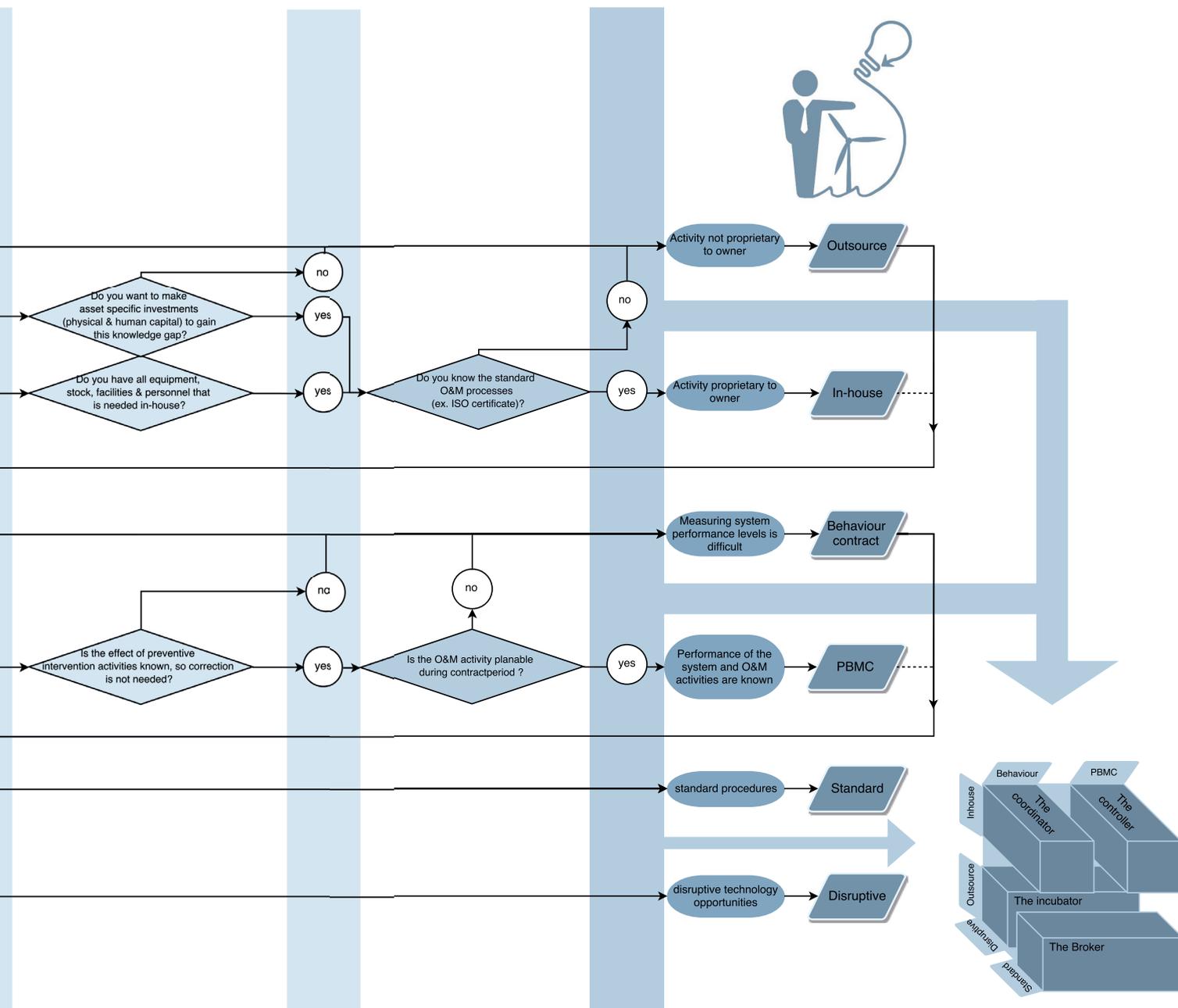


Figure (49). Result of the final decision-making flowchart

activity. The answers on the decision-making variables in the stream will define the option of a PBMC or the behaviour contract. If the in-house option was derived from the first stream, the second stream will still give a possible outsourcing solution, which will be important data for the possible sourcing strategy scenario. Next, In the last stream, the owner needs to look at the innovation level in the industry. Finally, every stream will give one outcome that can be translated on the axis in the sourcing scenario matrix, which is presented in the right corner below.

Different requirement levels (killer-, recommended - and optimisation-) are highlighted by the darkness of the blue coloured vertical lines. This gives the flowchart the ability to show the owner different weights of the outcome (the outcome is 'needed', 'recommended' or 'optimal').

In the left corner of this page, the legend is presented.



7.4 Validation of the final model

Running the decision-making flowchart that was based on the contract theories through the cases already created an on-going process of validation steps and adaptations of the flowchart. This section first discusses the perspective from the owner of the third Dutch wind farm which is still in its warranty. This will help to find consistency in the answers that derive from the flowchart. Secondly, also the sourcing scenarios will be validated by interviewing the OEM on his perspective on the possible sourcing scenarios in practice.

7.4.1 From the perspective of the new generation windfarm owner

During an interview with the wind farm owner of the third, and newest wind farm of the Netherlands, the steps in the flowchart were again discussed. This wind farm owner also owns the wind farm that was researched in Case 1, so he has already experienced a post-warranty sourcing process before. This third wind farm is operational since 2015 and is still in its first warranty period but will eventually also face the same post-warranty sourcing decisions as the other cases (Netherlands Enterprise Agency, 2015 & 4cOffshore, 2017).

The owner's first remark is that it is possible that a shift occurs from one scenario to another. During the sourcing scenario of Case 1, he identified himself more with the Coordinator scenario than with other scenarios. When looking to the future and with their new knowledge on the third wind farm, they say that they may consider the same scenario for their newer wind farm.

Furthermore, he acknowledges that the proprietary nature of the complexities of the owner, the knowability of the turbines and new innovations are indeed three main aspects that are weighted during their own process in practice. He emphasized the fact that governmental influence (subsidies & plot) and the financial pay-offs in the decision flowchart are still missing but constitute important parameters. Without the internal financial influences and external governmental influences, the flowchart can give outcomes that could not be implemented in practice.

The question is whether the owner will follow the same sourcing process with this new wind farm as executed with the older wind farm in Case 1. The owner explains that both his old and new wind farm have the same turbines, same OEM, same offshore distance and the same warranty SAA contract. The biggest difference is the age of the wind farm and the structure of the owner's consortium. For the Wind farm Case 1, the owner is fully responsible, takes all the financial risks and is able to decide on its own. The new wind farm is owned by a consortium with multiple owners that spread the risks. When an owner works in a consortium with other owners, steps in the decision-making flowchart can be answered with a 'yes' by one owner but answered with a 'no' by the other. Together, both owners need to define the post-warranty sourcing scenario. In this case, the flowchart can be used to detect differences and comparisons between the answered questions within the consortium. In this case, the aim of the flowchart changes towards a tool that can be used to make the partners within a consortium aware of their individual possible future scenario and aligning their outcomes.

Using the decision-making flowchart at this moment for the new wind farm will not be needed because the loan is not yet paid off and the 2-year-old turbines are still on high performance and create a high energy output. The owner that was interviewed believes that a lot will change in the offshore wind industry, which makes it difficult to look at possible sourcing scenarios right now. Though, the owner predicts that new innovations in CMS's and for example drones, make more performance data available. This data could lead to a decreased information asymmetry and risk aversion. By operating two main Dutch wind farms, the owner predicts economy of scale and a wider range of available data, which contributes to the characteristics of The Controller scenario.

Regarding the role of the OEM, the owner believes that the OEM will collect as much data as possible during his current O&M activities. This will contribute to their competitive position in the offshore industry market, which can create an extra aspect that needs to be weighted in the decision-making process in the future. It could be interesting to research how this competition between OEM's and owners will evolve in the future and how it could have an effect on the information asymmetry, risk aversion, goal conflict and uncertainty.

7.4.2 The scenarios from the perspective of the OEM

The OEM that was interviewed sees similar scenarios in the offshore wind sourcing strategies of multiple owners. The OEM works with a wide range of owners that all have different proprietary nature and knowledge about the performance of their wind turbines. The OEM that was interviewed noticed three main scenarios. Firstly, the OEM identifies the investor/developer who wants security due to financing reasons and prefers a long-term full scope warranty contract.

Then, due to the zero bid market we are approaching now, owners try to drive down costs to win the next tenders. In this second scenario the owner will have a full scope short-term contract, around 5 years, and then afterward they take the offshore logistics and back-office activities in-house. In this scenario the OEM is still present on site but only invoiced on a time and material basis. So the OEM is still executing the work on an exclusive basis but with a behaviour contract instead of a PBMC.

According to the OEM, the third scenario for the owner consists of the utilities who just want a warranty period for a very short time (2 years). During this warranty period the OEM and owner already work in mixed teams, where the employees of the owner are trained during offshore turbine maintenance tasks. After this warranty period, the owner has gained enough knowledge to take over the full O&M. By comparing the viewpoints and defined scenarios of the OEM with the four scenarios that result from this thesis, three strong similarities can be identified.

- (1) The risk averse investor/developer scenario can be compared with The Broker, who prefers a long-term PBMC contract and is not able or is not willing to take activities in-house in the near future.
- (2) The second scenario according to the OEM, can be compared with The Coordinator scenario with multiple behaviour-based contracts but coordinated by the owner.
- (3) The utilities with short-term contracts can be compared with The Controller who has a lot of knowledge about the performance of the windfarm because of close cooperation and training during the warranty period. This owner wants to take control over its wind farm as fast as possible and has the proprietary nature to do so.

The Incubator scenario could not be directly linked to one of the scenarios defined by the OEM. The Incubator scenario is derived from literature and was not acknowledged in practise during the interview with the OEM. A possible explanation could be that this scenario assumes presence of disruptive innovations that change the functions of the system.

7.5 Added value

In this paragraph, the contribution of the research to offshore wind energy, other industries and the body of research will be discussed.

7.5.1 The added value in the offshore wind industry

There are different ways in which the decision flowchart and the four scenarios contribute to offshore wind. The research mainly contributes to a more efficient scoping of the current PBMC in the post-warranty future, so that O&M costs can be minimized while keeping the performance high.

Secondly, the decision-making flowchart creates structure to wind farm owners during the sourcing process for the new O&M phase. By focussing on their proprietary nature, knowability of their turbines and innovation dynamics in the market, the wind farm owner can clarify the decision variables and possible outcomes, which creates a structured and transparent decision process. Third, the flowchart allows decision outcomes to be compared and qualitatively weighted against each other, which contributes to a clear view on the current O&M possibilities and illustrates a pathway from one scenario to another.

The decision flowchart can also be used as a tool for the OEM to categorize his different owners (demand) and find different approaches in each owner scenario. This improves the OEM's understanding of the goals of the owner and the risks the owner needs to take.

The scenarios visualize a future perspective that can be valuable for the position of new individual service providers in this market. There are a lot of individual service providers in the onshore industry but in the newer and heavier offshore wind industry are still only a few ISP's. There is a lot of potential for these ISP's if the owners take more risk in-house and outsource smaller execution parts with behaviour-based contracts. The decision flowchart shows what the owner needs to create such a scenario.

7.5.2 Generalising results and applications to other industries

During this research, the focus was on the offshore wind industry. However, application of the flowchart is not limited to offshore wind and can be used elsewhere without major modifications.

From contract theory, the three main decision-making variables were the proprietary nature of the owner, the performance of the wind turbines and the innovation dynamics. The proprietary nature of the owner is a decision-making variable that can be applicable for all kinds of owners in all kinds of industries that have to decide between the in-house option and the outsourcing option for their activities. The performance of the wind turbines is a specific question in the offshore wind industry. But if it is called 'The performance of the asset', it can be applicable for all industries that are working with physical assets. The last decision variable is the innovation dynamics and is only valuable in industries with a fast changing environment and high tech innovation opportunities. To decide if the decision flowchart and scenario outcomes could be used for other industries, this industry needs to meet the following constraints:

- The owner within this industry needs to have the in-house & outsource option and may be effected by asset specificity, frequency of transaction and uncertainty.
- The industry is able or could be able of working with KPI's to keep the PBMC option in the flowchart. Here the information asymmetry, risk aversion and goal conflict could play a role between the owner & contractor.
- The industry needs to work with physical assets that need corrective and preventive maintenance to keep it on the right performance level. Due to high downtime costs, preventive maintenance is an essential factor in the offshore wind industry. The flowchart will work more optimal if the industry that is used as a case, also has the urge to innovate in preventive maintenance instead of only doing small corrective maintenance tasks.
- The industry is influenced by technical innovations and a changing environment that could lead to higher environmental risks within a contract period.

Examples of other industries that could meet these requirements include large-scale solar, the Oil & Gas industry, the Rail & Road industry and maybe parts of mechanical engineering industries. It is important that it is possible to split the O&M activities according to the Six stage model. With this model one can split the O&M in different steps from the vision of the company to the execution of the work on site.

7.5.3 Contribution to the body of research

This research provided a comprehensive framework in a field where knowledge is not yet standardized and structured. The combination of transaction cost theory and agency theory for a sourcing task has been used in other industries, but not in offshore wind energy.

The theories are used to define the boundaries of a firm and to define the nature of a contract respectively. Interestingly, unlike other industries, the level of innovation is high in offshore wind energy and this affects the previous theories.

In particular, it appeared that the variables in agency theory are all affected by the level of innovation; parties become more risk averse or risk seeking, it was shown that quick dynamics in the information asymmetry arise, future goals are changing and uncertainty increases.

Furthermore, the decision-making flowchart structures the relevant decision making variables of both theories that can be used to define new sourcing options for heavy assets in a fast changing environment. The sourcing model that was derived from these theories could contribute as a method of applying both theories in practice during a sourcing process.

7.6 Limitations

This section contains limitations of the research project. First, limitations that arise from data availability are discussed. They are followed by more general remarks that treat validity of conclusions and the extent to which this research can be generalised.

Data gathering and processing led to several limitations due to confidentiality and availability issues, which will be discussed here. Foremost, due to the confidentiality of the contracts of both cases, it was not possible to discuss detailed knowledge of the content of these contracts. Because there are only a few wind farm owners it is easy to trace information back to the owner of the wind farm, which might harm its competitive advantage. The wind farm owner of the second case is currently in the sourcing process, therefore the results will only be available for the public when a decision is made in 2018. Nonetheless, background knowledge of the content of these contracts could be used to write this research and to understand the viewpoint of the OEM and the owner.

Furthermore, as described in the introduction of this research, the O&M offshore industry is a young and fast changing industry, which leads to limited data on the actual lifetime performance of the wind turbines and limited research on the total O&M phase on a strategic level. This leads to constraints on the technical level and leads to a limited amount of resources in the strategic sourcing field.

Other limitations concern the extent to which the research can be generalised and the impact of assumptions and choices that have been made throughout the project.

First, this research only focuses on the Dutch offshore wind industry, which allowed close to home interviews and easier scheduling of meetings to discuss the flowchart. This leads to conclusions that can be used for the Dutch offshore wind industry, and requires more work before it can be generalised to international context. Limiting the scope to the Netherlands also created difficulties in the number of possible cases that could be performed because at present there are only three main operational Dutch wind farms.

Second, it is worth mentioning explicitly that the research excludes the warranty period. The effect and impact of decisions and developments during this phase are not included in the final scenarios. Sometimes the owner and the OEM already have an optional post-warranty sourcing future in mind when the wind farm is not even operational. As explained by the OEM of the two cases, the length of the first warranty period depends on the view of the owner for the future. This initial view is not included in the scenarios of this research, which might have impact an impact.

Third, the subsidies of the government and the loans are not included in this research. The research is built on the Agency theory and transaction cost theory that defined the three streams used in the flowchart. When the wind farm is not subsidized anymore and when the assets are paid off, the dynamics in risk and responsibility changes. It can for example be an incentive for the owner to look at other sourcing strategies if their is a financial need due to the higher O&M costs of an older windfarm and a decreasing energy output. In this research, the reason for use of the flowchart is assumed to be the expiring warranty period and not a financial consideration of the owner.

Next to the limitations that have impact on the conclusions and the limitations of data collection, there are also limitations regarding the available time and personal research capabilities. The amount of time scheduled for this master thesis is bounded by the study programme, which makes a focussed goal and clear scope necessary. Additionally, a qualitative research with a design-oriented case study approach presents certain limitations in its usage, most importantly the sensitivity and observational skills of the investigator.

8. Conclusions

A decision-making framework was composed that can be used to find a sourcing strategy for the O&M of offshore wind farms in the post-warranty future. With this decision-making framework, wind farm owners will be able to reduce their O&M costs and stimulate efficiency and innovation. The answer to the main research question below will be discussed in line with the set of sub-questions that were set up.

‘How to scope performance based maintenance contracts for the post-warranty O&M phase of offshore windfarms?’

The first sub-question that was answered was formulated as: ‘What are the main offshore wind farm O&M activities?’ To answer this sub-question, the cost-drivers and their influence on the performance of the wind farm needed to be researched.

(1) During the warranty period, all O&M activities are outsourced to the OEM with ‘availability’ as the main performance indicator. Availability is derived from three components: accessibility (offshore logistics), maintainability and reliability. During the decision-making period for the post-warranty future, owners are looking at the best O&M strategy. It was found that the total O&M activities can be divided in the turbine maintenance, the offshore logistics and the back-office maintenance operations. These activities in relation to their main cost drivers are discussed by using the Six Stage model that visualizes all the possible O&M steps within a performance based maintenance contract. During the research, it became evident that the three main activities have a lot of overlapping parts but all contribute to the general performance indicator ‘availability’ (which can be segmented into accessibility, reliability, maintainability and condition measurability), yet in a different way. Offshore logistics contributes mainly to the accessibility of the wind farm, the actual turbine maintenance contributes to the reliability and maintainability of the turbines and all the back-office maintenance operation activities contribute to the reliability and the condition measurability. Increasing the maintenance efforts will improve the overall availability of the wind farm but will also increase the required resources to be devoted to O&M.

For this reason, it is important to know the cost-drivers of the main O&M activities. It was identified that the location of the wind farm and the weather forecasting are cost-drivers that play the most important roles for the accessibility of the wind turbines. Secondly, the risk type items (gearbox, generator and rotor), the offshore work hours and the heavy equipment are leading cost-drivers for the maintainability of the wind turbine. The costs for condition monitoring and performance measurement systems are essential to collect and interpret data to define the reliability of the turbines.

In the decision-making process for the post-warranty sourcing strategy, the effects of the various activities on the performance indicator should not be overlooked because this will eventually have an impact on the scope of the performance based contract.

The second sub-question that was answered was formulated as: ‘Which contract theory variables are relevant in the decision making process for a new sourcing strategy for offshore wind farm O&M?’ To answer this question the contract theory was researched and combined, which led to a structure that was used in the process.

(2) Transaction cost theory was used to define the most efficient boundaries of the owners firm. Here, the asset specificity, uncertainty and frequency of the transaction are indicators that have an effect on the cognitive and constructive complexity of the transaction. The owners’ techniques and processes that are needed to transfer or take in-house a good or service were identified as the ‘proprietary nature’ which is an important decision variable when choosing between the O&M in-house or outsource option.

Next, when an O&M activity will be outsourced, there is a choice between a traditional behaviour based contract and a performance based contract. A performance based contract requires a relatively high level of knowability of the performance compared to behaviour based contracts. The Six stage model was used to explain the relationship between the performance requirements and the final performance output. The degree

of knowability of performance was assessed with agency theory and is the second decision variable. The owner has to be aware of the fact that there is a high knowability of the performance when information regarding the performance data is available and can be interpreted and planned by the owner after the warranty period. To gain knowledge about this performance data, the owner should already learn from the performance details during the warranty with the OEM.

In addition, it was found that the type of contract is influenced by the dynamics of the environment. Within a performance contract, the aim is to keep the asset available according to the agreed performance level and function. The owner has to be aware that if the performance requirements change due to new innovations, the performance outcome becomes difficult to measure, which has a negative effect on a performance based contract.

In short, the contract theory variables that the owner needs to be aware of and examine during the decision making process for a new sourcing strategy for offshore wind farm O&M are the 'proprietary nature' of the owner, the 'innovation dynamics' of the industry and 'the knowability of the performance' regarding the wind turbines.

In the third sub-question it was asked what the decision-making options are within a performance-based contract for post-warranty O&M of offshore wind farms. This question combines the O&M activities and characteristics with the variables derived from contract theory.

(3) The third sub-question was answered empirically during the case studies. The answers on the first two questions from the literature study were combined in a draft version of the decision-making framework. This draft framework was complemented by knowledge of experts in one of the three main activity fields (turbine maintenance, offshore logistics & back-office activities). Both of the cases led to new adjustments of the decision-making framework to create a constant process of improvement of the design

The decision-making options within a performance based contract for post-warranty O&M of offshore wind farms are all captured in the flowchart that is composed and tested in the cases. The decision-making options together lead to the final four scenario's that can be a possible sourcing strategy scenario after the warranty period. The final four scenarios for the post-warranty O&M of offshore wind farms from the owner's perspective are:

- The Broker Scenario: The outsourcing option is recommended for the Broker because the complexities during the transaction of the O&M activities are not proprietary. There is information asymmetry and/or a lack of asset specificity that leads to cognitive and constructive complexity for the Broker. Also he is partly rational and limited in solving complex problems and processing data, which leads to uncertainty. The broker can still choose between a PBMC and a behaviour contract. If the performance of the total system can be measured and predicted, a performance based approach with the OEM can be the future option, but the broker has to be aware of the fact that the activity is not a core activity of its business. In this scenario there are no asset specific investment needed for new innovation and the function of the asset does not change during the contract period.

- The Incubator Scenario: The complexities during a transaction of the O&M activities are not proprietary to the Incubator. There are cognitive and constructive complexities for the Incubator in its dynamic environment. The incubator is limited in solving complex problems and processing data but is able to attract specialists who can. In this scenario, there are disruptive technologies in the field so specialized and dynamic companies need to bring their fresh knowledge to the incubator. He can still choose between a few contractors with a PBMC or a bigger network of contractors (ISP's) with behaviour based contracts. The Incubator needs to be aware that innovation is not always guaranteed and even can lead to higher uncertainty and new possible asset specific investments.

- The Coordinator Scenario: The coordinator is capable of taking the main O&M activities in-house because the historical data of the performance is known, the data can be interpreted and there are no extra asset specific investments needed. Unfortunately, not all the system data regarding the performance of the turbines is known but he is able to coordinate a wide range of contractors with the help of a behaviour-based contract for execution activities. The coordinator has to be aware that he needs to guarantee potential innovative knowledge within smaller behaviour contracts and he needs to minimize information asymmetry.

- The Controller Scenario: The Controller is capable of taking the main O&M activities in-house, but

he is also able of outsourcing with a PBMC because the performance of the turbines and O&M activities are known. The Controller has the knowledge about the impact of possible failures, the effect of corrective and preventive maintenance interventions and about the ability to plan activities. Next, he is aware of the impact of possible new innovations on the turbine performance and can control possible innovation dynamics with sub-contractors.

The last sub-question was set up to explain how do the sourcing scenarios are influenced by the decision-making variables and explain what the consequences are.

(4) This last sub-question comprised the influence of the sourcing strategy scenarios on the decision-making variables that were derived from literature. The final categorisation of the three decision-making streams was linked to the contract theory and the usage of the flowchart.

By introducing different requirement levels (killer-, recommended - and optimisation-), the flowchart had the option to show the owner different weights of the outcome. This is an important improvement because if the owner is capable of a scenario, it does not mean that this scenario is 'recommended' or 'needed'. The wind farm owner in the first case ended up in 'The Coordinator' scenario. The wind farm owner in the second case showed a mix between 'The Coordinator' scenario and 'The Incubator' scenario. The answer in the first case was more static in comparison with the more hybrid scenario in the second case. This is because the first case did not show differences between the outcomes of the three activities (turbine maintenance, offshore logistics & back-office activities) and the second case did. If the owner can identify himself with one of the scenarios but is willing to consider one of the other scenarios, he is able to look back at the requirements to find a bottleneck that defines the current situation. This makes that the four sourcing scenarios are influenced by the questions in the three main streams in the model and the consequences can be found in their contract theory characteristics.

It is important to note that the four scenarios that were derived in this research show more flexibility in practice then when drawn in a simplified three-dimensional model containing four individual blocks. This visualisation supports the creative task of discovering and structuring possible scenarios in theory but can lead to difficulties when linking to practice. It was shown that there are multiple flexibilities in the model that create overlapping parts or spaces (see section 7.2.1).

The four sub-questions together can give an answer to the main question of this research; How to scope performance based maintenance contracts for the post-warranty O&M phase of offshore wind farms?

This can be done by identifying the proprietary nature of the owner, the knowability of the performance of the turbines and the innovations dynamics within the industry on the decision-making moment. This has to be identified for the turbine maintenance activities, offshore logistics and back-office activities. If the owner uses the decision-making flowchart that is presented in this research, he will be able to identify the sourcing scenario that is suitable, recommended or even needed in the post-warranty O&M phase. Taking these steps will scope the performance based contract that was used during the warranty period to a new post-warranty sourcing future.

To grasp the essence of the conclusions in this research, the following statement from the perspective of the owner can be used:

'Do what you know, understand what they show, and learn when winds of change blow.'

First, the owner needs to have ownership over the complexities regarding the transaction of an O&M activity if the owner wants to be able of an in-house option ('Do what you know'). When outsourcing with a PBMC is preferred, there needs to be an understanding of the performance and current condition of the turbines ('... what the turbines show...'). Thirdly, the owner has to learn when winds of change blow, in this fast changing and innovative industry.

The owner can choose its own direction and can use this research as a guideline to structure the sourcing process when considering possible post-warranty sourcing scenarios.

9. Recommendations

The process of answering the main research question and sub-questions generates more questions that could be explored through further research. This leads to several recommendations to both improve the flowchart and to guide efforts that attempt to generalise its outcomes.

The decision-making flowchart is composed in such a way that it is possible to use O&M activities from another industry to be the input for the model. In this case, it is recommended to examine the applicability of the flowchart and further define requirements of the input. In addition, by increasing the amount of different cases, new adaptations can be done which further optimizes the flowchart.

Testing the four scenarios in other industries to research differences and similarities between different case outcomes might also generate new insights and help with validation of the model. It will be interesting to see when the scenarios are applicable for a particular industry and when it does not fit the industry's characteristics. In the added value chapter of this research, some requirements were already given.

In the offshore wind industry, the amount of individual service suppliers is still limited in comparison with onshore wind. In the Incubator scenario, innovation and competition could be guaranteed by a network of multiple ISPs. An interesting research topic could be the position and perspective of these individual service suppliers in the offshore O&M industry and the impact on the current situation.

Secondly, it is possible to look at the future sourcing scenarios from the perspective of the OEM. The OEM can have different roles within the post-warranty period, as discussed during the validation with the OEM of the Dutch wind farms. In each role, different capabilities could be needed.

Next to recommendations that guide efforts that attempt to generalise the outcomes, also recommendations to improve the flowchart can be examined.

At first, it is important to emphasize that the flowchart was based on two contract theories and tested in two extensive case studies. After both case studies, the flowchart was adapted. The aim of interviewing the owner of a third wind farm as a validation step was to find similarities in comparison with the extensive case studies. Though, it is difficult to find similarities because this particular wind farm is still in its warranty for quite a while, so the owner does not have the need to look for a new sourcing scenario. This way of validating made it difficult to find validation results.

Validating the qualitative flowchart was also difficult because of the limited amount of wind farm owners in the Netherlands. Ideally, more case-studies would be used.

Secondly, it is recommended to improve the flowchart by quantifying the financial outcomes based on the LCoE and by including the subsidy, taxes and loans. By quantifying the scenarios, it could be possible to identify 'the best' option based on the financial needs of the owners of all the cases that run through the model. When this is quantified, the decision model will not only be used when a warranty period ends, but also when there is a financial benefit of entering into a new contract. For this improvement, it is important to find enough financial data of the entire life cycle of the project.

Thirdly, the decision-making model is presented as a flowchart in this research. This way of presenting a decision model has limitations. One of the limitations is the oversimplification of the steps because it has to be a clear and easy to use tool. Although the flowchart can be used within a few minutes and creates awareness of possible sourcing scenarios for a wind farm owner, it would be interesting to explore more detailed methods.

10. Discussion

To answer the research question and to achieve the research objective, a qualitative and empirical research strategy is used. The nature of the research was comparable with a design-oriented research because the two cases and interviews led to new adjustments of the decision flowchart, which created a constant process of improvement.

Interesting complementary insights could be generated by performing a quantitative study. For example, the quantified O&M costs and performance of the turbines can be used to decide which scenario is the best (note however that data on wind turbine performance in the Netherlands is still limited). As experienced in this research, obtaining specific performance data from OEM's and wind farm owners could be difficult due to the contract confidentiality and heavy competition in this fast developing industry.

If the owner uses the decision-making flowchart that is presented in this research, he will be able to identify the sourcing scenario that is suitable, recommended or even needed in the post-warranty O&M phase. The owner can choose its own direction and can use this research as a guideline to structure the sourcing process when considering one of the four post-warranty sourcing scenarios. The scenarios should be interpreted as a post-warranty O&M sourcing situation, based on the decision-making variables derived from the literature study and interviews in this research. The user of the flowchart needs to understand that the scenarios are not the 'best' scenarios but are a categorisation of sourcing combinations in four different ways.

The order of the three streams in the flowchart is an important factor that may not be ignored. The flowchart starts with a focus on the owner's capability. If the core capabilities of the owner are clear, the framework zooms in on the knowability of the specific asset. If the activities are not complex for the owner it does not mean that the performance of the wind turbines can be known. This shows that there is no interrelation between the decision variables (axes in the matrix). If the preferred (out-) sourcing option is known, it is necessary to look at the level of innovation dynamics of the industry because this has a direct effect on the outcome uncertainty and the possibilities to measure changing performance requirements.

So, in this research the categorisation of the decision variables is important but there is not a strong interrelation between the axes. Potential interrelations could be found by examining more owners of different wind farms in the post-warranty period with the composed decision flowchart.

In addition, the user of the decision flowchart has to keep in mind that the scenarios are based on two contract theories and the three main offshore O&M activities that were examined. More depth can be obtained by incorporating more detailed O&M activities and exploring other possibly suitable contract theories.

Next, it was found that the OEM experienced similar scenarios in the sourcing strategy process for the different owners that they work with. However, the 'Incubator' scenario could not be directly linked to one of the scenarios defined by the OEM.

This is because the OEM predicts that most innovation developments will occur in the foundation design. This prediction can be seen as questionable because the two wind farm owners and an expert in the offshore logistics industry predicted a high level of innovation in turbine blade optimisation, condition monitoring systems, integrated offshore logistics and multiple innovative inspection technologies such as drones. It could also implicate that the interviewees had different perceptions on what the word 'disruptive technologies' means and how it could affect the sourcing strategy.

Also, the flexibility of the scenarios presented as four blocks in a three dimensional model was explained in paragraph 7.2. Capturing the four scenarios in a graphical 3D picture with three axes shaped a rigid figure of the real situation. For a thorough understanding of the possible scenario outcomes, it was important to discuss the degree to which the spatial boundaries between the scenarios are pliable in reality. The flexibility of the spatial boundaries were discussed in text but also drawn in figures. The reader of this thesis has to be aware that the researcher is limited in transferring words to a picture. In addition, figures can be misunderstood because it requires interpreting skills from the reader.

The conclusions of the literature study and observations during the case interviews that led to the four scenarios could have possible limitations regarding the sensitivity and observation skills of the investigator. The flowchart had to be used by the owner for the three O&M activities that were defined in this research.

During the interviews it became clear that asking the questions in the flowchart three times, can lead to misinterpretations in the answers of the owner. Also it creates a less structures, more chaotic conversation. Designing a flowchart with the three activities already interweaved in the questions would have helped to structure the interviews.

Secondly it is important to mention that the researcher of this thesis can be biased because of the order of the cases. Choosing the second case as the first case, could maybe lead to different answers and adaptations of the flowchart, which creates a different input for the next case. The flowchart itself can also lead to question-order bias, because owners can be primed by the words presented in questions that impact their thoughts and attitude.

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