MASTER THESIS

The design of an analysis methodology for Dutch offshore wind

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Colophon

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Title: The design of an analysis methodology for Dutch offshore wind

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Summary

With constant growing energy needs the Dutch government is at a turning point in the energy transition. The chance to make real steps towards a future where energy is completely generated sustainably is now. In order to realise such a future, ambitious targets have to be set. For the near future the Dutch government set the renewable energy generation target at 14 % renewable generated energy in the year 2020 and 16% in the year 2023 (SER, 2013). With the current renewable energy generation percentage of only 4.53% of the total end use energy, the challenge to get to 14% sustainable energy target in 2020 is substantial (leefomgeving, 2013; CBS, 2014). For the offshore wind sector the ambitions are at least as ambitious. In eight years, 2015-2023, the goal is to increase the generation capacity of offshore wind with a total of 3450 MW to a total of 4500 MW (I&M, 2014). For the total energy use in the Netherlands this would mean an increase of 4.9% renewably generated energy by offshore wind alone, in comparison to 2013 energy use and in case only fossil fuel sources would be replaced (CBS, 2014).

In order to clarify the relevance of this paper a short section of page 17 of the guiding document for offshore wind development in the Netherlands, the Rijksstructuurvisie wind op zee, is quoted. *"The total area of the selected areas Borssele, IJmuiden Ver, Hollandse Kust and Ten Noorden van de Waddeneilanden is around 2900 km^2. This 2900 km^2 is the gross area. For the selected area goes that there are still uncertainties in relation to spatial planning with other usage functions and the marine ecosystem. This will have as effect that parts of the selected area for offshore wind will drop out. This mainly concerns: safety zones, ecological area and corridors for small and recreational shipping"* (I&M, 2014). In this short section the Dutch government indicates that they did not take all factors into account during the selection of the offshore wind areas. As a result these factors and their preconditions have to be taken into account in later phases requiring extra efforts of the developers. Furthermore it is interesting to see is how the Dutch government directly reference to the exclusion of factors that proved to be of significant influence to location suitability. These "concerns": safety zones, ecological areas and corridors are incorporated in the analysis model developed in this thesis and were identified to have a major impact on location suitability. If one, or more, of these parameters are present at an evaluated location, the location would be qualified as not suitable for the development of offshore wind. Therefore their inclusion proved to be of importance to the analysis model. The analysis methodology presented in this research stresses the importance of carrying out a complete analysis and therefore an integral analysis model for development of offshore wind has been developed.

With a structured step-wise research approach this research provided answers to the research question. In the first step, the actor analysis evaluates nineteen actors and comprised these actors into five main actors. Evaluating the point of view of the main actors on five different topics resulted in three points of interest. These points: data quality, uniformity, spatial pressure/overlap were used as guideline to keep the analysis structures scope-relevant.
During the second phase of the research, research step 2, 3 and 4, an analysis model for the analysis of offshore wind was designed. Overall the analysis model looks into the evaluation of offshore wind from four different perspectives: park & turbine, economics, wind & ocean and foundation & seabed, given in figure 6. As basis for the model, 59 factors and analysis points were used. Recapping on the research from the first phase, the analysis model is evaluated on completeness and relevance to the scientific and corporate sector.
During the third phase of the research, step 5 and 6, the research evaluates the input data used for the analysis. The reliability and integrity of the input data is assessed in this analysis. Through value aggradation to individual data points required to perform the analysis. The input data is quantified and data completeness can be indicated with the results of the suitability

analysis. With the indication of data completeness the reliability and data availability on two or more possible offshore wind sites can be benchmarked. In the last chapter before the conclusion the research recaps on the points of interests found in the first research phase in order to validate the completeness and relevance.

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1. Introduction

Current world scale developments in the energy sector are massive. Real term worldwide investments, according to the world energy investment outlook, have doubled in the last 14 years to a total of 1600 billion dollar with an expected rise to 2000 billion dollar in the year 2035 (IEA, 2014). With such a size the energy market is one of the drivers of the modern economy. Apart from the big size, the market is highly active. According to Scopus, scientific research on energy as a topic resulted in 25.358 related hits for the year 2013 alone. Wherever there is an active market and extensive research, ambitious targets inevitably follow. For the energy market the transition to a more renewable energy mix is one of the most ambitious challenges in the near future. (IEA, 2014).

Set in March 2007 and enhanced in 2009, the EU set the "20-20-20" targets as the three key objectives for the near future. Of the three 20-20-20 targets the key objective set for the energy market of the EU is: *"raising the share of EU energy consumption produced from renewable resources to 20%"*. (EU, 2014). For the Dutch government this key objective is imbedded in the Dutch energy generation target. The Dutch renewable energy generation target is set at 14 % renewable generated energy in the year 2020 and 16% in the year 2023 (SER, 2013). Knowing that, in 2013, the renewable energy generation is, only, 4.53% of the total end use of energy, the challenge to get to 14 % in 2020 is substantial (leefomgeving, 2013; CBS, 2014)

From the renewable energy generation sectors, wind energy is the second largest in the Netherlands (CBS, 2014). Wind energy is dominated by onshore wind. In the year 2012 land based wind energy was more than five times larger than offshore wind (CBS, 2014). Although the offshore wind sector is smaller in comparison to onshore wind, the aspirations for the offshore sector are big. In eight years, 2015-2023, the Dutch government aims to increase the generation capacity of offshore wind with a total of 3450 MW (I&M, 2014). For the Netherlands this would mean an increase of 4.9% renewable generated energy, in respect to 2013 energy use and in case only fossil fuel sources would be replaced (CBS, 2014). Combined with current operational capacity, the total offshore energy capacity would increase to a total of 4450 MW in the year 2023 (I&M, 2014). Reaching this goal is an ambitious and very interesting challenge for the offshore wind sector.

1.1. Problem definition

The Dutch government set the objective to increase the offshore wind capacity by 3450 MW. In order to increase offshore wind capacity, collaboration between science and the offshore industry is of high importance (Arshad, 2013). Models for the integral analysis of possible location for offshore wind could benefit from this collaboration. When looking into scientific literature, more indications of the importance of theoretical models for the analysis of location suitability for offshore wind come into view.

Indications, such as later described, hinting at the importance of theoretical models can be found in multiple research papers. The papers indicate the importance and impact of spatial and technology specific variables on the viability of offshore wind farming (Raadal, 2013; Tsu-Ming, 2013; Rehana, 2013). Although the impact of individual and connected variables is stressed, the scope of most scientific research is limited to a very specific area. In the conclusion or discussion section of these papers, the researchers often advices further research on a broader scale. In the reviewed research, research into the interaction of the researched variables on a broader scale is often advised (Byrne, 2003; Arshad, 2013). The impact of individual and connected variables can be found in the research of Raadal et al. In their conclusion they mention: *"specific platform/foundation steel masses are of high importance for the overall relation to offshore wind"* (Raadal, 2014). According to the research the impact of foundations, a highly connected variable, is estimated at 24% of the total cost of construction (Raadal, 2014). The choice and design of foundation types are analysed thoroughly in current research. Multiple overviews, effect and technical improvement studies focus on offshore turbine foundations. Most of these papers scope to very specific interactions between location, depth and wind. A study of a broader setup on, for example, the impact of location choice on overall foundation costs can not been found.

When reviewing research that does focus on evaluation methodologies for offshore wind farms, a general trend in research focus can be observed. Research, in general, focuses on partial areas of a wind farms (Rehana, 2013; Tsu-Ming, 2013) or on individual turbine design (Byrne, 2003; Raadal, 2014). For example Raadal et al. focuses on an LCA study of offshore wind farms but he only focuses on one specific wind farm build-up. In the end he stresses the need for further research into assessments strategies of offshore wind farms of different setups (Raadal, 2014).

When reviewing research with a broader scope, research scoped on the cost analysis of offshore wind comes into view. A good example of a cost analysis research is the research from Ashuri et al. their research is focused on decreasing the specific energy costs of offshore wind (Ashuri, 2013). The group conducted research on optimum wind turbine design in relation to relative energy costs. Although the study includes a comprehensive analysis of the dimensions of a wind turbine, it focuses on variations in one type of turbine only. The parameters of the wind farm as a whole and the turbine type are kept constant. Although this is a good approach for the evaluation of wind turbine costs parameters, the overall wind farm variables are excluded.

1.1.1. Knowledge gap

When searching scientific literature for research on a comprehensive evaluation method for the viability of location for offshore wind and the effects of the location on the output of the offshore wind farm, no adequate method could be found. Research on the topic is fragmented or is scoped to a small part of the overall picture. Zaaijer et al. already hinted at this knowledge gap in science in his paper in 2009. He states that; *"preliminary design results and development risks of new technologies are rarely addressed in current research"* (Zaaijer, 2009). Were Zaaijer et al. hint at the knowledge gap Theunissen et al. deepen it. They stress the need for further research into the topic and they indicate an additional concern. They say: *"for wind farms comprising of hundreds of turbines, reliability of the obtained numerical data becomes a growing concern"* (Theunissen, 2014). In their research they indicate that the research into an evaluation model needs to contain data validation to a certain degree. In combination with the previously described problem definition the knowledge gap can be identified. This research will address this literature gap.

1.1.2. Research question

This Master's thesis research focuses on this knowledge gap and strives to add knowledge to science. The research focus was on the design of a method for the integral analyses of offshore wind farms. The method includes the analysis of individual turbine specifics with overall wind farm variables and natural parameters. Additionally data requirements and data accuracy was assessed. The research presents an integral analysis structure with which future researchers will be able to analyse and indicate suitability, data quality and availability. In order to achieve this the following research question and sub questions was posed:

What is a good analysis method for assessing the technical and economic feasibility of offshore wind farms in the Dutch offshore area?

Two sub-research questions were formulated in order to give more structure to the research. The sub-research questions posed are:

- *What are the most important factors that influence the feasibility of an offshore wind farm and how do they correlate?*

- *Which datasets are required to predict offshore wind energy production capacity more reliably and what are the preconditions for the required data?*

1.2.Relevance

This sub-chapter the project relevance is described, the relevance is split in the scientific & societal relevance and the corporate relevance.

1.2.1. Scientific & Societal relevance

As indicated in the paragraph knowledge gab there is a gap in knowledge concerning the analysis of offshore wind farm planning methodologies. A comprehensive evaluation method for the theoretical viability of location for offshore wind and the effects on the output of the offshore wind farm is missing. The current frameworks for quick scanning the Dutch offshore region for wind farm development areas are lacking, fragmented or of low value. By targeting that gap in knowledge this Master's thesis research adds relevant knowledge to science.

Whereas the scientific relevance of the Master's thesis research is addressed in the problem definition, the societal relevance needs further elaboration. The set target of 14% renewable generated energy in the year 2020 is for society of high importance. Increasing the supply has been on the agenda of the Dutch and European government for years and they intend to reach this goal by increasing the capacity in offshore wind generation. If the 2020 energy requirements are to be met, the renewable energy generation capacity has to increase. This Research methodology ambitious goal can only be reached in the given timeframe if improvements are made in the area of preliminary design (Zaaijer, 2009). With these improvements the ease and speed of location analysis for offshore wind will be enhanced and this would result in an improved chance that the target will be reached.

For the Master Sustainable Development, track Energy and Materials, the research topic offshore wind is close to heart. Multiple lectures and assignments have been given on wind energy development, analyses studies and method development. Through combination of wind and analyses, this Master's thesis research is in correspondence with the Master itself.

1.2.2. Corporate relevance

From a corporate viewpoint the Master's thesis research is also of relevance. During the preface of writing the Master's thesis, in collaboration with Fugro, I contacted several market parties in order to identify market interest. The contacted market parties were; NIBC, a Dutch investment bank active in offshore wind, TKI wind op zee; a platform for offshore knowledge sharing, ECN; a company researching energy and IHM; a Dutch governmental platform sharing information of the Dutch offshore area. During the first contacts the indicated companies, were very interested in the project and indicated that they saw potential.

2. Method & research concepts

The methodology chapter of this Master's thesis research is split in two parts. At first the methodology as in the overall is described. Secondly the methodology applied in the individual research steps is described.

2.1. "Overall"

The design of the proposed Master's thesis research was based on a mixed method approach. The applied research methods are both quantitative and qualitative. The choice for the mixed methods approach was a consequence of the two-phase design of the research. In order to design a reliable analysis method both data validation, in this research mostly qualitative, and research design, mostly quantitative, had to be applied. The two-phased design is one of the innovative approaches of this Master's thesis research. Applied methods during the research are: semi-structured interviews, multi-criteria analyses, benchmarking and empirical data collection. During the research additional methods were selected based on insights gained during research. Examples of additional research methods are: relational theory and correlation research.

The figure below gives an overview of the conceptual framework of the research. The main goal of the Master's thesis research was to design the three "blocks" leading from data to the preliminary design. The research steps related to the conceptual framework are described in the sub-chapter "Individual research step description.

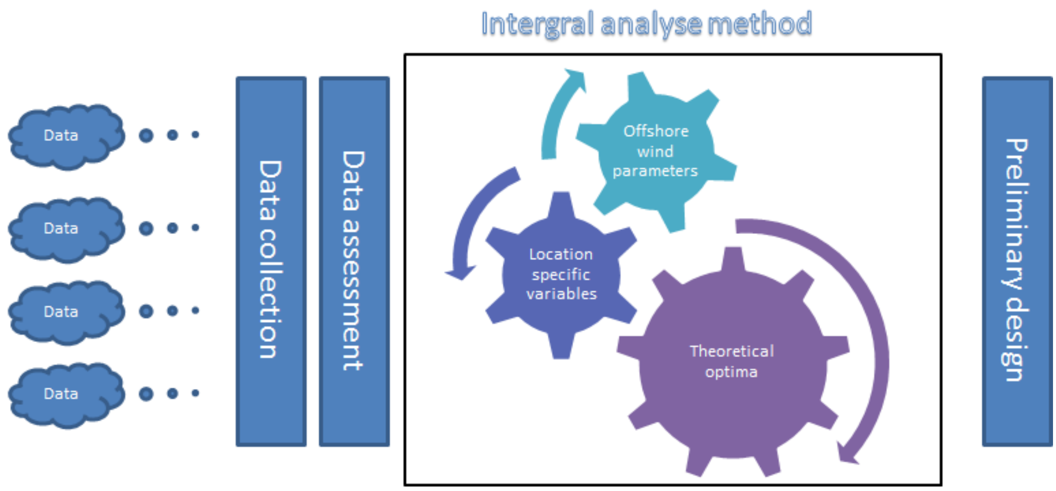

Figure 1: Conceptual framework

Overall the research can be divided into two main topics. These topics are assessment method development and data assessment & development. The two main topics are closely linked to the sub-research questions. The first sub-research question is answered in the main topic: assessment method development and the second sub-research question is answered in the main topic: Data assessment & development.
In order to make the research more pragmatic the two main topics are divided into more practical research steps. The research steps are:

Main topic: ***Assessment method development***
Step 1: Actor analysis, interviews with experts and background research
Step 2: Factor selection and development
Step 3: Wind farm assessment methodology design
Step 4: Analysis method design validation

Main topic: ***Data assessment & development***
Step 5: Data requirement mapping
Step 6: Data assessment & development

The research steps above are closely interlinked. When an interlinked research step was researched the main focus was on the first research step, into chronological order. In order to give a better picture of the relation between the research steps an overview is given in figure 2.

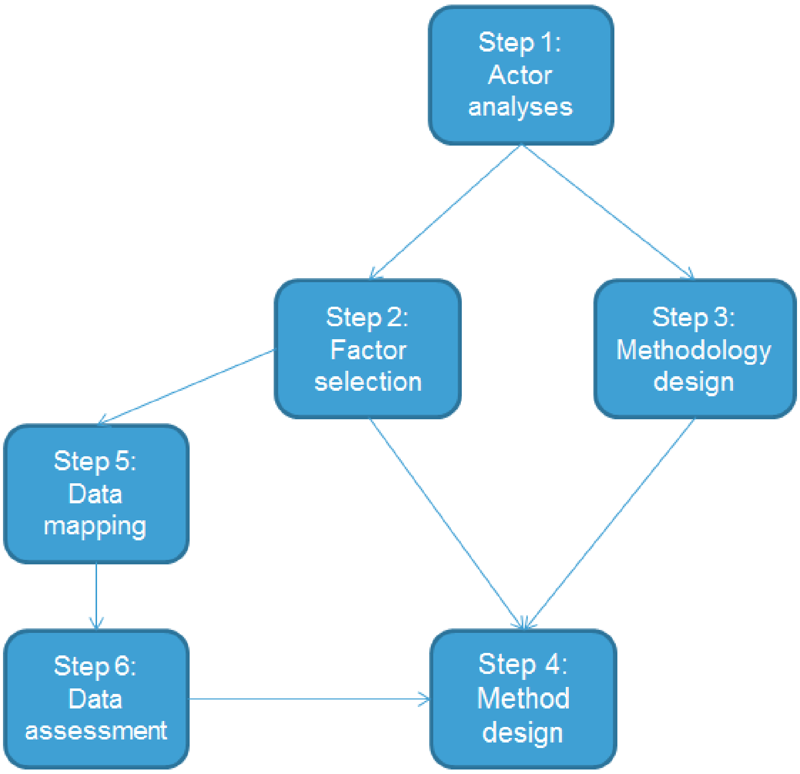

Figure 2: Relation between the research steps

Figure 2, above gives a clear image of how the research is interlinked. Effectively research step 2, 3 and 6 have an effect on research step 4. Keeping research step 4 as step 4 was a deliberate choice. During the research the combination of information from research step 2 and 3 in research step 4 validated the completeness of the previous research steps. This feedback effect ensured that during research step 5 the right data requirements were mapped. Input of step 6 on step 4 enhanced the method design.

2.2. Individual research steps

This sub-chapter contains the description of the applied methods in the individual research steps.

2.2.1. Actor analysis, interviews with experts and background research

The first step focuses on gaining an insight into the background of offshore wind park design. In order to achieve this goal an actor analysis was performed. An indication of the importance of the actor analysis can be found in the quote of Mitrof: *"Stakeholder analysis is used mainly to support project management and design activities as well as strategic advice in the corporate sector"* (Mitrof, 1983). He argues that stakeholder analysis is mainly used as a supporting tool for designing activities in the corporate sector. Several other authors emphasize that public policies are generally generated within networks in which multiple actors are interrelated in a more or less systematic way (Rhodes, 1992; Klijn, 1997; De Bruijn, 1999). Combining these

arguments when performing a stakeholder analysis. Strengthens the relation between the research and the scientific and corporate sector, which directly strengthens the relevance of the research and ensures that the focus of the research is on relevant topics.
The performed analysis was based on a stakeholder analysis set-up, added to the method of Bots et al. and Mitrof et al. and then specifically the imperative approach (Mitrof, 1983; Bots, 2000). The main goal of the research step was to investigate what the main interest points of the different actors in the offshore wind sector are. With these identified main interest points it was possible to scan for topics of high value to the actors.
The scope of the actor analysis was national level. Further boundary conditions were the selection of the nineteen primary actors. This selection was based on literature review. Composing the nineteen primary actors into six composed actors was based on literature review and expert judgement.
With the six composed actors identified, the next step was identifying the main focus points of the composed actors. The applied methods for gathering data for the analysis were semi-structured interviews and expert judgment. The main goal of the analysis was to review, in depth, the main areas of interest of the composed actors. For five of the six actors, excluding "other", an actor representative was selected and interviewed. During the interviews the main focus was on the topics; *main interest, objective, existing or expected situation gain and gab, causes, possible solutions, actor validation and main focal points*. The actor analysis topics were based on the method of Mitrof in combination with topics selected through literature review. (Bots, 2000; Mitrof, 1983; Delft, 2010).
With the results mapped, points highlighted by multiple actors, so-called overlapping points have been identified. Through researching the background of the overlapping points, points of interest were identified. These points of interest are used throughout the research to ensure the link with the scientific and corporate sector.

2.2.2. Factor selection and development

The second step of the research focused on factor selection and development. This research step is in close relation with research step one. Further deepening on the first research steps the second research step selects the factors influencing offshore wind. The selection is based on factors highlighted of high importance in the semi structured interviews, scientific literature and by expert judgment. The factors are grouped per item and correlated per group. The way the factors are grouped is based on a combination of relational theory and correlation research. The research step gives an overview of the selected factors grouped per topic. With the grouped factors the correlation of the different actors is indicated.

Foundation

The focus for the category *foundation type* is on the selection of the factors that are of main influence on the selection of foundations types for certain locations. The main sources of information were Fugro project descriptions, experiences of Fugro with offshore surveys, literature research and expert judgment. During the research lists of Fugro's project experiences in the offshore wind sector were reviewed. With these lists the influencing factors having an influence on the choice of foundation type were selected. The selected factors can be found in chapter 4.

Wind and ocean

For the *wind and ocean* category the focus was on the factors influencing offshore wind from the perspective of ocean and the conditions. The selection criteria were: factors highlighted in scientific literature, Fugro project experiences or in expert judgment. The selected topics of the wind and ocean category are: wind, usage limitations and ocean. The selection of the topics is based on the regularity in which they, in combination, were found in scientific literature (Madariaga, 2012; Berkhuizen, 1988; Thomsen, 2001; Rehana, 2013). For the wind topic the focus was on selecting only the most relevant factors influencing the metrology, oceanographic and geospatial factors. Individually selected factors can be found in chapter 4.

Park and turbine

For the park and turbine category the focus was on the factors influencing a wind turbine or a park of wind turbines. The main sources for the selection of the factors were scientific literature and Fugro project experiences. The park and turbine category is split into the three topics: turbine, production and park. Although the category is called park and turbine the topic production capacity topic is incorporated at this point of the analysis, because of its close relation to the other two topics. The selected factors can be found in chapter 4.

Economics

For the economics category the focus was on the factors that have influence on the financial flows related to offshore wind. The selection of the factors in this category is limited to the factors that, according to scientific literature had the main impact on the financial flows. The economics analysis is based on a cost/benefit approach. Therefore the two main topics are: costs/benefits. Reviewing standard cost/benefit approaches in combination with literature review and Fugro experiences were the main sources for the factor selection. The individual factors can be found in chapter 4.

2.2.3. Wind farm assessment methodology design

The third step of the research focused on assessing offshore wind farm analysis strategies and designing an analysis model. Designing the analysis model was done in two phases.
In the first phase literature was reviewed on relevant analyses strategies for offshore wind parks analysis. Through the analysis of these, often fragmented or partial, analyses strategies. The best options/combination of analyses methods were chosen. Effectively this research step resulted in an analysis model where the selected factors, selected in step 2, are connected. The connections between factors are supplemented with evaluation points where evaluation of the connection factors is necessary. The relations between factors, evaluation points, evaluating factors and influences on factors are assessed through reviewing scientific literature and applying relational theory. With relational theory the selection between relevant and less relevant connections between actors and combinations was made. Only relations indicated of relevance to the model were included in order to keep a transparent overview.
In the second phase of research step 3, the factors and analysis points connected in the first phase of the research step, were given their preconditions. Through the evaluation of the preconditions the model evaluates the acceptance based on the factors/analysis point. The preconditions set to the factors/analysis points were selected based on scientific literature, interviews with experts, benchmarking and analysing analysis studies and project experiences of Fugro.
Completed, the two research phases resulted in an analysis model capable of an integral analysis of a location for offshore wind. The analysis model consists of 60 factors/analysis points and has a wide acceptance of locations. The results of this research step can be found in chapter 5.

2.2.4. Analysis method design validation

The fourth step of the research focused on the validation of the analysis method design, designed in research step 3. Recapping on the research done in step one, two three, five and six, step four will ensure the incorporation of all the important factors and evaluates the completeness of the analysis strategy. More specifically the research step recaps to the selected points of interest and evaluates their incorporation in the analysis model and data assessment. The sources for this research step are scientific literature, the topics of main interest found in research step one and the analysis model design in the later research. The main method of evaluation was based on reviewing scientific research. Even though the research step is posed as the fourth step the step will be conducted parallel with step five and six. This is due to research design, given in figure 2. Step four reviews step one two and three before starting at step five and six in order to perform the first completeness check. When step five and six are complete the step re-evaluates the completeness of all the steps. The double check approach was selected as the best method of research.

2.2.5. Data requirement mapping

The fifth step of the research focused on mapping data requirements for the analysis method. First the overall data requirements for the analysis was identified. This identification was based on the selected factors selected in the research of step two. The selected factors in combination with the analysis of the used data sets in the reviewed scientific literature and expert judgment from Fugro, resulted in a table with a list of datasets required for the optimal analysis. Second the relative importance of data sets were quantified. Quantification of the importance of data sets was done in combination with the relative importance of the factor. The relative importance was determined based on the analysis of 16 analysis studies on offshore wind. Although the evaluation of the importance and frequency of occurrence of the factors/analysis points in the analysis methodology reviewed, the relative importance was quantified. The combination of these steps resulted in an overview which contained the required and the relative importance of the datasets as a whole and the importance of the individual analysis points and factors.
The importance of research step 5 is the ability to identify the importance of missing, incomplete, fragmented or unreliable data. With that ability and the relative importance of the missing data points it becomes possible to evaluate the data used as source for the analysis based on quality and completeness. This evaluation ability is of added value because of the frequency of missing or incomplete data in offshore wind analysis studies. The indication of missing data found in scientific literature is in accordance with the point of interest indicated in step 1. Additionally data mapping gives an insight into the importance of the missing data set to the analysis as a whole. Last, the mapped and quantified data requirements makes it possible to analyse location based on data availability.

2.2.6. Data assessment and development

The sixth step of the research focused on data evaluation. Per dataset literature indicating requirements set to data use were reviewed. The focus of this step was to identify the criteria set to the data used in scientific literature. Through identifying these criteria, parameters could be set to the datasets. They indicated the minimal requirements the dataset has to meet in order to be of value to an analysis. Mapping these requirements is of importance because with this approach not only the required data is mapped, but also the requirements set to the data itself are mapped. Setting parameters to the data used as input for the analysis significantly improves the reliability of the analysis (Angelakoglou, 2013).
Per dataset parameters were set, identifying specific requirements that the dataset has to meet in order to quantify as reliable. This in combination with the previous research step makes it possible for the analysis strategy to evaluate the data completeness/requirement and sets a standard for the data required to perform the analysis. The selection of these criteria is based on scientific literature review and project experiences of Fugro and expert judgment.

3. Actor analysis

In this chapter the findings of the actor analysis are described. The actor analysis, stakeholders analysis, has as goal to identify the actors concerning the development of offshore wind and their main interests. With the main actors and their interest identified, incorporation of the interest of these actors in the further design of the analysis strategy will be possible. Effectively this analysis ensures that the designed methodology will contain relevant analysis options for the main focus points of the reviewed actors.

3.1. Offshore wind sector and actors

The offshore wind sector is a diverse and active field. Countless parties have their own perceptions, interests and dedication to the topic of offshore wind. The Dutch government for example set development targets of 3450 MW additional capacity of offshore wind in the year 2023 (I&M, 2014). Projects such as; marine spatial planning (IMARES) and the North Sea agenda 2050 (Min I&M), only further emphasizing the involvement of different actors and their interest. In order to ensure the analysis strategy is in line with the current offshore wind situation and incorporates the most pressing issues, the actor analysis selected the nineteen most prominent actors (Kern, 2014). Incorporation of more that nineteen actors was impossible due to time constrains. The selected actors are given in the table below.

Table 1: Composed actor composition

Composed Actor	Investors	Constructors & operators	Designers	Environment	Government	Other
Sub-actors	Investing banking	Windmill fabrication	Windmill design	Birdlife	Spatial planning	Fishery
	Project financing	On-site construction	Park optimisation	Fish and underwater life	Economic affairs	Transport
	Financial project management	Offshore utility	Implementation design	Recreation	Infra & environment	Offshore operations
						Research and development

The table above shows the nineteen selected actors. Reviewing the actors on five topics, perspective, main interests, dedication, main objective and main focal point, made it possible to merge the actors in six main categories (Delft, 2010). Effectively these categories form six composed actors; investors, constructors & operators, designers, environment, government, investors and others. Through in-depth research into the six composed actors, the main focus points of the actors are identified. Figure 3 shows the composed actors.

Figure 3: Composed actor structure

3.2. Offshore wind actors and their focal points

With the nineteen individual actors composed to six main actors analysis is manageable. During in depth research the actors were analysed on eight topics. According to Bolts et al. the actors could best be analysed based on; main interest, objective, existing or expected situation gab, causes, possible solutions, critical or non-critical actor, dedicated or non-dedicated actor and their main focal point (Delft, 2010; Bots, 2000). The topic of main interest focuses on the main interest of the actor in relation to the offshore wind. The topic of objective; focuses on the main objective in the area of interest that, according to the actor, requires attention. The existing or expected situation gab; covers the main concern in regard to the objective the actor has. The topic causes; focuses on the cause for the existing or expected situation gab. The possible solutions; focuses on the possible solution for the improvement of the current situation of the objective from the perspective of the actor. The topic of critical/non-critical actor; evaluates the ability of the actor to prevent the successful implementation of a development in the sector and therefore reviews whether or not the actor is critical for the implementation of development in the sector. The topic of dedicated/non-dedicated actor; evaluates the willingness of the actors to commit its resources in the pursuit of the most optimal situation from the actors perspective. The topic of main focus points; evaluates were the main focus of the actor currently lies (Delft, 2010; Bots, 2000). The table below gives the overview of the different composed actors, the analysis topics and outcome for the different actors.

Table 2: Composed actor analysis results

Actors (Composed)	Main Interest	Objective	Existing or expected situation gab	Causes	Possible solutions	Critical non-critical actor	Dedicated non-dedicated actor	Main focus point
Constructors & developers	Situation specifications	High quality data availability	Data fragmentation	No uniformity	Data quality enhanceme nt	Non-critical actor	Non-dedicated	Data quality and availability
Financial sector	Cost/benefits	Profitable situation	Economic analysis is of low reliability	Bad quality of data	Enhanced data assessment	Critical actor	Non-dedicated actor	Reliability
Governmental sector	Spatial planning And meeting target	Good insight in spatial influencing variables	Data and analysis fragmentation	No uniformity	Evaluation spatial overlap	Critical actor	Dedicated actor	Spatial overlap & data reliability
Environmental sector	Environmental impacts	Minimum environment al impact	Possible environmental impact	Lacking uniformity	Location selection on minimum impact	Critical actor	Dedicated actor	Spatial overlap & data reliability
Others	Spatial use	Minimum impact on spatial use	Multiple location use	Spatial pressure	Enhanced spatial planning	Non-critical actor	Non-dedicated actor	Offshore overlap

In the table above the analyses of the six actors based on the eight topics is visualised. In the table above it can see that the focus of the actors vary. For the topic of main interest the focus of most actors is related to location specific/spatial information, except for the financial sector. The main reason for the overlapping focus is caused by the importance and influence of location choice for different activities (Byrne, 2003; Rehana, 2013). Location suitability or spatial conflict is not the main interest of the financial sector, their main focus is on the profitability of the activity from a financial perspective. For the topic objective there is an overlap for the sectors; government, environmental. Their objectives focus on the spatial use and spatial impact of offshore wind. Interesting is the focus of high quality data availability of the constructor &

developer actor. The actor indicates that the quality and availability of data on the Dutch offshore area requires attention. Apparently data inconsistency is a common complication for the constructors and developers (Tsu-Ming, 2013). For the topic existing or expected situation gab the lacking uniformity is indicated as the most prominent situation gap. In total three actors identified lacking uniformity. Lacking uniformity, for these actors, causes distrust in data and delays due to deviating situations on the location. For the actors, distrust in data and delays are very important influences on development (Balks, 2014). For the topic causes two points were indicated with frequency; bad data quality and lacking uniformity. In total 4 out of 5 actors indicated lacking data and uniformity as of importance. Due to the frequency of identification lacking data quality and uniformity is indicated as a point of interest. From the topic possible solutions the main identified topics were enhancing data quality and spatial planning. The indication of these points further hints on the importance of data and strengthens the need for a uniform analysis strategy. For the topics, critical/non-critical actor and dedicated/non-dedicated actor, no surprising results were found. The last topic: main focus points mainly indicated the need for available and reliable data preventing overlap and improving reliability. This topic is explained more thorough in sub-chapter 3.3 points of interest.

3.3. Points of interest

In the previous sub-chapter the composed actors were evaluated on eight topics. In total three different overlapping points were found. The first overlapping point was quality of data, the second uniformity in analysis and data and the third was the concerns for spatial overlap/spatial pressure. In-depth analysis of the overlapping points aims for identifying specific points of interest. The identified points of interest target the specific pressure point at the centre of the overlapping points.

The first overlapping point; quality of data, was highlighted in table 2 at the topics: objective, existing or expected situation gab, causes, solutions and main focal points. The composed actors indicating the importance of the quality of data were: constructors & developers and the financial sector. The link between the two actors concerning data quality is not far-fetched. Both actors rely heavily on predictions and models for the analysis of suitability of offshore wind. The financial sector basis its analysis on a cost-benefit approach. Reliable and precise data are of main influence on the reliability of the output of these types of analyses. (Madariaga, 2012; Rehana, 2013; De Prada, 2014).

Constructors & developers focus their analysis and designs on in situ-situations. Reliability, accuracy and precision of the actual situation where wind farm is to be build are of high importance for the sector (Lee, 2013). With both composed actors relying on high quality data, data quality itself is indicated as a point of interest.

The second overlapping point; uniformity, was highlighted in table 2 at the topics: existing or expected situation gab, causes and main focus points. The composed actors indicating the importance of uniformity were: the constructors & developers, governmental sector and the environmental sector. For these actors uniformity has the same meaning, but the actors encounter the problem of uniformity at different points. The constructors & developers encounter the problem of uniformity in relation to basic data (Madariaga, 2012). Data inconsistency was highlighted as the main uniformity problem from the perspective of the constructors & developers. Examples of data inconsistencies are: different positioning of pipes and cables in the North Sea area, bathymetry and location of shipwrecks. Varying positions in basic data can have significant influence on the positioning of wind turbines. In order to illustrate data inconsistency an example is added in appendix I. Further details on data requirements and assessment can be found in chapter 7. For the governmental and environmental sector the focus point of uniformity is related to data inconsistencies. The difference between for the experience of lacking data uniformity for these sectors is that they have a more spatial conflicts relations problem to data uniformity. An example of lacking

uniformity in spatial planning can be found in appendix II.
From the three actors having uniformity as overlapping point, two actors have spatial uniformity as an overlapping point. Therefore spatial inconsistency is indicated as a point of interest. Uniformity of data, confronting point for the actor constructors & developers, is not added as an individual point of interest but is added to the point of interest data quality due to the overlap.
The third overlapping point; spatial overlap/pressure, was highlighted in table 2 at the topics: main interest, causes, and possible solution and main focus points. The composed actors indicate the importance of spatial overlap/pressure were the actors: governmental sector, environmental sector and the composed actor others. The overlapping point is closely related to the second point of interest; spatial inconsistency. The main difference between the two points is that this point, spatial overlap/pressure, focuses on spatial overlapping and not on spatial inconsistencies. Good examples of spatial overlap are: overlapping of oil/gas pockets under wind farm locations or conflicting situation with a safety zone. To illustrate spatial overlapping an example is added in appendix II. When looking at spatial overlap from this perspective the link between actors is evident. Future expectations are that conflicting interest due to increased activity in the North Sea are expected to become a bigger issue (Min. V&W, 2009). Based on the indications and the expectation of increasing importance in the future, data mapping is identified as a point of interest.

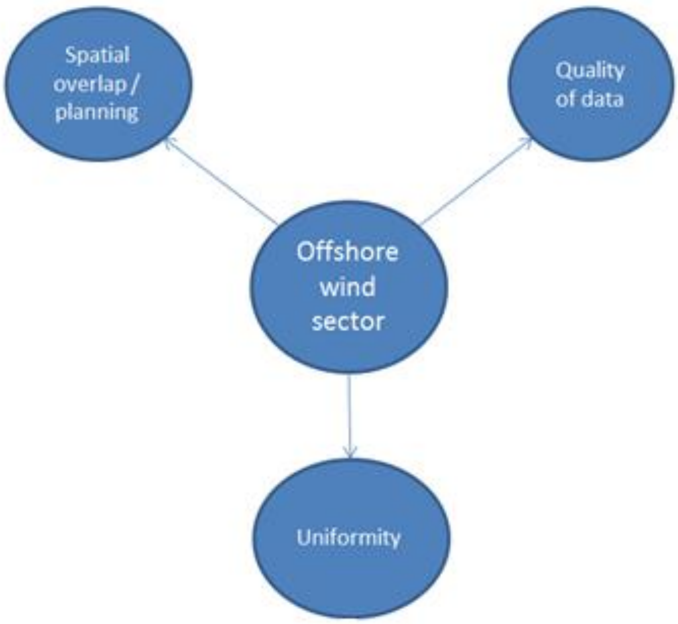

Figure 4: Schematic overview point of interest

The figure above, figure 4, gives a schematic overview of the overlapping points and their related points of interest. Through recapping on the points of interest, chapter 8, the methodology stays connected to the offshore wind sector. And through that connection the research remains corporately relevant and scientifically relevant. It also guarantees the coverages of the most pressing points in the sector and current science.

3.3.1. Incorporation points of interest in the research

Incorporation of the points of interest in de data points is spread through the report. Next to point of incorporation in the report. The method of incorporation of the different points of interest differ. Most prominently the points of interest are incorporated in chapter 8, analysis method design validation. In this chapter the designed analysis model is re-evaluated based on the identified points of interest found in this chapter. Based on this analysis, which effectively recaps on the points of interest and evaluates the incorporation, the focus, link scientific research and interest of the corporate sectors is guaranteed. An additional beneficial effect is how the recapping guarantees the incorporation pressing factors for the reliability of the analysis model.

4. Factor selection and development

Whereas the previous chapter indicated the most pressing viewpoints from an actor analysis viewpoint, this chapter gives the results of the factor selection and development. The factor selection and development gives the basis variables for the analysis evaluation scheme which is designed in chapter 5. To clarify the factors discussed in this chapter some factors are put in italic.

4.1.Factor selection

The factors influencing offshore wind are divided in four main categories. The categories are: foundation and seabed, wind and ocean, park and turbine and economics. With these four categories the most common split of the factors found in scientific literature was chosen (Herbert, 2005; Zaaijer, 2009). In total ten topics and thirty-one factors were selected and incorporated in the analysis. The selection criteria for the factors can be found in chapter 2: methods and research concepts sub-chapter 2.2.2. Information about factor interactions related to the individual factors can be found in chapter 5: Windfarm assessment methodology design & benchmarking.

4.1.1. Foundation and seabed

The first category is the category: *foundation and seabed*. The category focuses on the factors related to the different foundation types and variable seabed conditions. In total the category consists of eight selected factors. Six of the eight factors are variable factors. This means they do not have a go/no-go precondition but they have parameters in which offshore wind is possible. Two factors are fixed factors. This means they do have go/no-go preconditions. The main goal of the category is to select the factors influencing location suitability from the standpoint of foundation and geographical preconditions.

Table 3: Foundation and seabed factors

Foundation preconditions	Geographical precondition
Soil profile	Subsurface structures
Local geology	Subsurface use
Regional geology	
Bathymetry	
Seabed features	
Foundation preconditions	

Table 3, above shows the eight factors of the *foundation and seabed* category. The factors are split based on two topics, foundation preconditions and geographical preconditions. The first topic focuses on the preconditions influencing the applicability of different foundation types. The first factor from foundation preconditions is the *soil profile*. This factor evaluates the soil profile of the direct location where the foundation is placed. It evaluates the type of soil and conditions related to the soil type (Byrne, 2003). The second factor is the *local geology*. The factor looks into the conditions and types of the different soil layers in the direct vicinity of the selected location. The term "vicinity" not only involves the horizontal but also the vertical axes, of the location where the foundation would be placed (Byrne, 2003). The third factor *regional geology* looks into the seismicity in the vicinity of the foundation and the evaluation includes risks of seismic activity (Alati, 2015). The forth factor *bathymetry* evaluates multiple parameters of bathymetry related to foundations. Evaluated parameters are depth to seabed, boulders and drop stones and currents (Alati, 2015). The fifth factor *seabed features* evaluates seabed features such as flatness of the seabed, wreck/UXO etc. The sixth factor considers the *foundation*

preconditions. Different foundation types have different preconditions and different applicability (Carswell, 2015).
The second topic, *geographical preconditions*, focuses on the geographical conditions influencing the applicability of offshore wind in the region. The focus is on features that hinder offshore wind at a certain location. The first factor of the topic, *subsurface structures*, focuses on human-made objects located at the seabed, old drill holes for example (Georegister, 2015). Even though old drill holes will not stop or ensure an offshore park, it is an influencing factor. Availability of data from the drill samples can be an interesting reference tool for the soil conditions. The second factor of the topic focuses on *subsurface use* (I&M, 2014). This factor focuses on the use of the subsurface. Subsurface usages such as sand mining or location where pipes and cables run over the seabed are undesirable locations for offshore development.

4.1.2. Wind and ocean

The second category, *wind and ocean*, focuses on preconditions related to the meteorology, surface usage and oceanographic data. The category contains three topics and eight selected factors. Three of the factors are variable factors, five are fixed. The variable factors are: wind, wave and current parameters. The fixed factors are environmental protection, shipping areas, indicated offshore wind areas and exploitation areas. The main goal of the wind and ocean category is to evaluate the suitability of locations from the perspective of usage and for the most optimal meteorological and oceanographic conditions for offshore wind.

Table 4: wind and ocean

Meteorological data	Usage limitations	Oceanographic data
Wind parameters	Environmental protection	Wave parameters
Meteorological conditions	Shipping areas	Current parameters
	Indicated offshore wind areas	
	Exploitation areas	

The table above shows the eight factors of the *wind and ocean* category. The factors are split into three topics: meteorological data, usage limitations and oceanographic data. The first topic focuses on meteorological data and contains two factors: wind parameters and meteorological conditions. The factor *wind parameters* is build-up of five different parameters. The selected parameters for the factor are: annual wind speed, average wind speed, monthly average, direction and height of measured wind. By reviewing multiple analysis studies it became clear that these parameters were most commonly used and were indicated as most valuable. Therefore these parameters were selected and set to the factor (Lee, 2013; Kurt, 2014). The second factor of the first topic: *meteorological conditions* focuses on the meteorological conditions at the selected site. It incorporates the meteorological conditions not concerning wind. The selected parameters are: temperature, sunlight, humidity and annual rainfall (Jiménrx, 2015).
The second topic: usage limitations focuses on areal overlap of different usage functions. The first factor of this topic, *environmental protection*, focuses on protected marine areas. An example of marine protected areas are the Natura 2000 areas (I&M, 2014). The second factor of this topic, *shipping areas*, focuses on the areas used for shipping. Incorporated shipping areas are shipping lanes and army exercise areas (I&M, 2014). The third factor of this topic, *indicated offshore wind areas,* focuses on the areas selected for the development of offshore wind. This factor is based on the indicated areas of the development of offshore wind in the Netherlands

(I&M, 2014). The fourth factor of this topic, *exploitation areas*, focuses on areas that are given a specific exploitation use other than shipping area. Examples are: constructed offshore wind farms, sand mining areas and offshore oil and gas platforms (I&M, 2014).
The third topic; oceanographic data, focuses on the conditions of the sea at the selected location. The first factor of this topic, *wave parameters*, focuses on the wave parameters at the selected site (Larsén, 2014; Benitz, 2014). Examples of wave parameters are wave height and frequency. The second factor of this topic, *current parameters*, focuses on the conditions of the sea currents (Larsén, 2014). The selected parameters of the current parameters factor are: strength and direction. An important reason for the incorporation of current parameters is their influence on scour effects around the windfarm foundation at the sub-sea level. This effect erodes the protective soil layer at the foundation base, influencing the stability (Larsén, 2014). By way of the analysis of these three topics and their factors the wind and ocean conditions influencing offshore wind are analysed.

4.1.3. Park and turbine

The third category, park and turbine, focuses on the preconditions related to individual wind turbines and overall windfarm build-up. The category contains three topics and ten factors, all ten factors are variable factors. The goal of this category is to evaluate the effects of different park setups and evaluate the influences of different turbine types. In the third topic the influencing factors on production capacity of an offshore windfarm are analysed. With the evaluation of all the factors the effects of different setups is analysed.

Table 5: Park and turbine

Park	Turbine	Production
Amount of turbines	Turbine type	Efficiency
Turbine to turbine distance		Transportation loss
Park area		Energy production
Distance to shore		
Grid connection point		
Wake forming		

Table 5, above shows the ten factors influencing offshore wind park and turbine build-up. The factors are split in three main topics: park, turbine and production. The first topic, park, focuses on the factors that influence an offshore wind park consisting of multiple wind turbines. The first factor of this topic, *amount of turbines*, focuses on different setups in turbine amount in the entire park. The second factor from this topic, *turbine to turbine distance*, focuses on effects of different distances between turbines (Folkerts, 2001). Different turbine to turbine distance is closely related to the first factor, *turbine amount*. But is added as a separate factor because of the additional impacts the factor has on effects such as wake forming and area coverage (Folkerts, 2001). The third factor of this topic, *park area*, focuses on the effects of different area sizes of an offshore wind park. The fourth factor of this topic, *distance to shore*, focuses on the different locations of an offshore wind park in relation to the distance the park would have to the shore. This factor includes the analysis of the length of a required connection cable to an onshore grid connection point (Tande, 2004; Ackermann, 2000). The fifth factor of the first topic, grid connection point, focuses on different options for a grid connection point and different options for the location of this grid connection point (Tande, 2004; Saccomando, 2002). This factor includes the onshore or offshore transformer station options. The sixth factor of this topic, *wake forming*, focuses on the effects of wake forming caused by the location, type and setup of the turbines in different setups of an offshore wind park (Dahlberg, 1992).

The second topic, turbine, focuses on the effects of different types and setups of the individual wind turbines. The first and only factor of the second topic, *turbine type*, focuses on the type of turbine chosen. The type of wind turbine influences: hub height, blade area, wind velocity optimum and wind power potential (Herbert, 2005).
The third topic, production, focuses on the energy production capacity of an offshore wind farm (Chehouri, 2015). The first factor of this topic, *efficiency*, focuses on the effects on efficiency of individual wind turbines and extrapolates this effect for the efficiency of the total offshore wind farm (Herbert, 2005). The second factor of this topic, *transportation loss*, focuses on the losses in transportation of the generated energy to shore and in the transformer (Perveen, 2013). The third factor of this topic, *energy production*, looks at the energy production from an integral perspective taking efficiency and transportation losses into account (Perveen, 2013). To illustrate the working principle of the production of energy through offshore windfarm, the figure below is added.

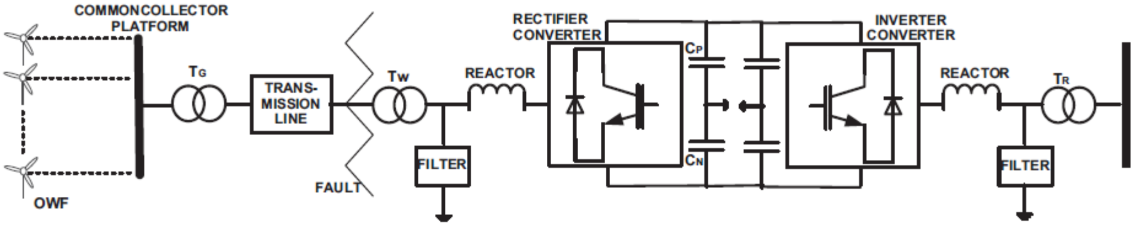

Figure 5: Block diagram of an offshore connection (Perveen, 2013)

4.1.4. Economics

The fourth category, *economics*, focuses on the economic analysis of an offshore windfarm. The analysis is based on a cost/benefit approach. The category is split into two topics: cost and benefit. Of the two topics all factors are variable factors. The main goal of this category is to evaluate the different effects economics have on the integral system. In order to achieve the goal, the category contains two topics and four factors.

Table 6: Economics

Cost	Benefits
Construction	Energy profits
Operation and maintenance	
Electrical infra-structure	

The table above contains the factors incorporated in the economics category. The category is based on a cost/benefit approach as can be seen in the split of the two topics, cost and benefit. The first topic, *costs*, focuses on the main costs related to the development of offshore wind. The first factor of this topic, *construction*, focuses on the costs in relation to the construction phase of an offshore wind project (Islam, 2014). The second factor of this topic, *operation and maintenance*, focuses on the costs related to the operational phase of an offshore wind farm (We@sea, 2013; Astariz, 2015). The third factor of this topic, *electrical infra-structure*, focuses on costs caused by the required electrical infra-structure support for an offshore wind farm (Kurt, 2014).
The second topic, benefits, focuses on the benefits related to the exploitation of an offshore wind park. The first factors of this topic, *energy profits*, focuses on the gains from the generated energy (Angelakoglou, 2013).

5. Wind farm assessment methodology design

In this chapter the design of the assessment methodology is described. The main goal is to compose an analysis model where all the, previously selected, factors are included and together design an integral model.

5.1. Selected factors, their interactions and composition

In the previous chapter the selected factors have been identified. Between the selected factors (thirty-one in total) interactions, correlations and relations are present. By way of combining relational theory with researching the interactions and reviewing analysis methodologies found in literature. Made it possible to connect the individual factors and design an integral model that can be used for the analysis of offshore winds suitability. Figure 6 below gives an overview of the analysis model with the relations between the different factors. Because of the size of the model the figure might be unclear and therefore a clearer version of the figure is added in appendix V.

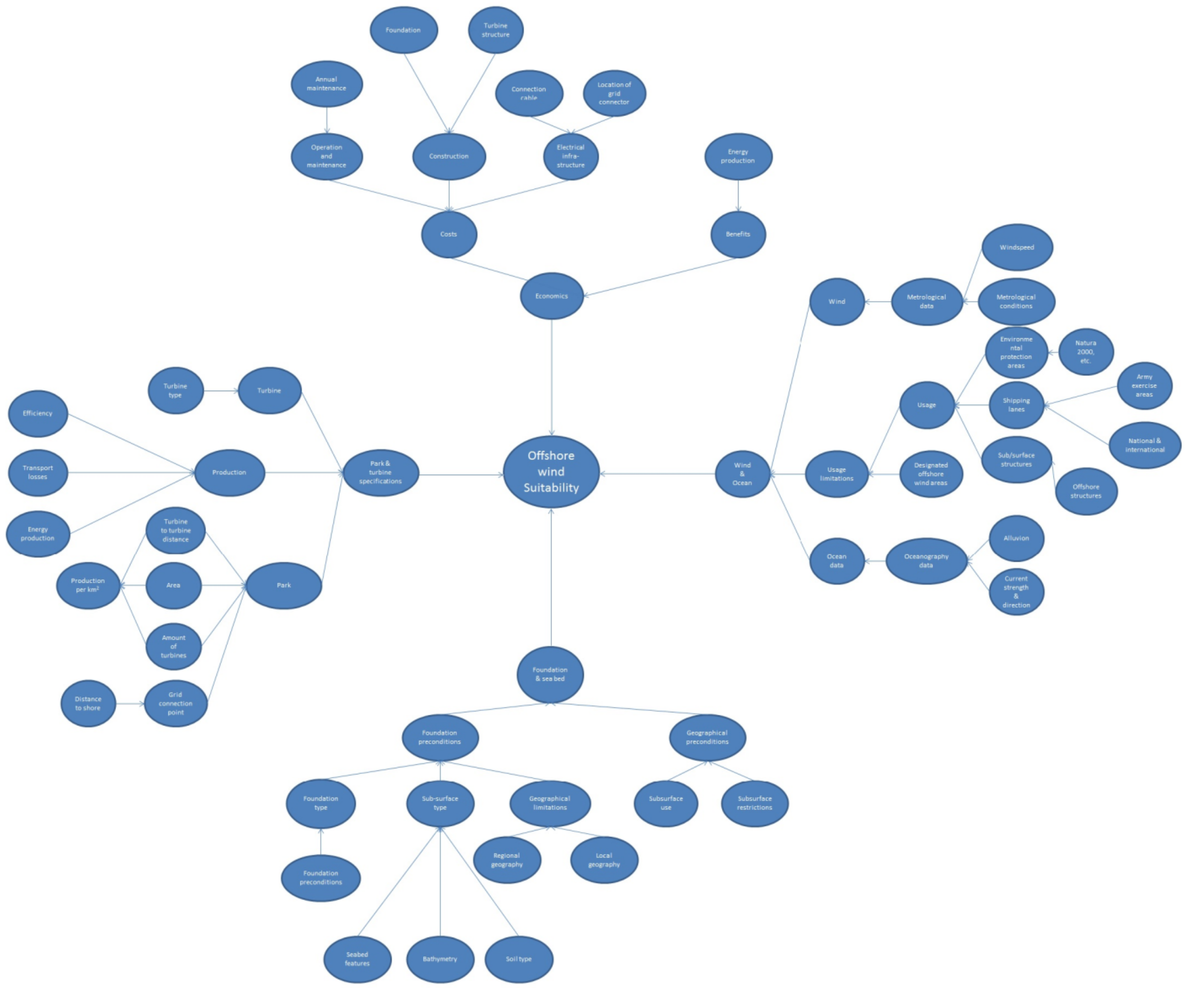

Figure 6: Total overview of the analysis strategy

The analysis model design is based on the four categories presented in the previous chapter. The design of the model is based on the most common scopes in scientific research. Most current research focuses on one of the four categories. This model combines these four categories and is the design strategy for the site selection of offshore wind based on the thirty-one selected factors. Site selection is of critical importance for the viability of offshore wind and has been researched for years (Berkhuizen, 1988; Thomsen, 2001; Lee, 2013). A good example that site selection for offshore wind has been researched for years is the research of Berkhuizen et al. from 1988. In their research they state that an analysis for offshore wind should start nationally, and afterwards the pinpointed areas should be analysed at a more specific level. Analysing at a more specific level means holding all restraints into account and complement these restraints with more general restraints such as distance between windfarms, distance between structure, telecommunication, nature reserves and largely populated areas etc. Finally the local situation has to be analysed in order to analyse the local feasibility (Berkhuizen, 1988). Although their research is over 27 years old the principle still counts. The following paragraphs focus on the four categories and their factor relations.

5.1.1. Foundation and seabed

The first category consists of the foundation & seabed category. The analysis model is based on the eight selected factors in chapter 4. These factors are split into two topics and relations are represented through connection lines between factors. To complete the model six evaluation points were added. In total the model contains 14 factors and analysis points. Together these factors, relations and evaluation points leads to the analysis model given below, figure 7.

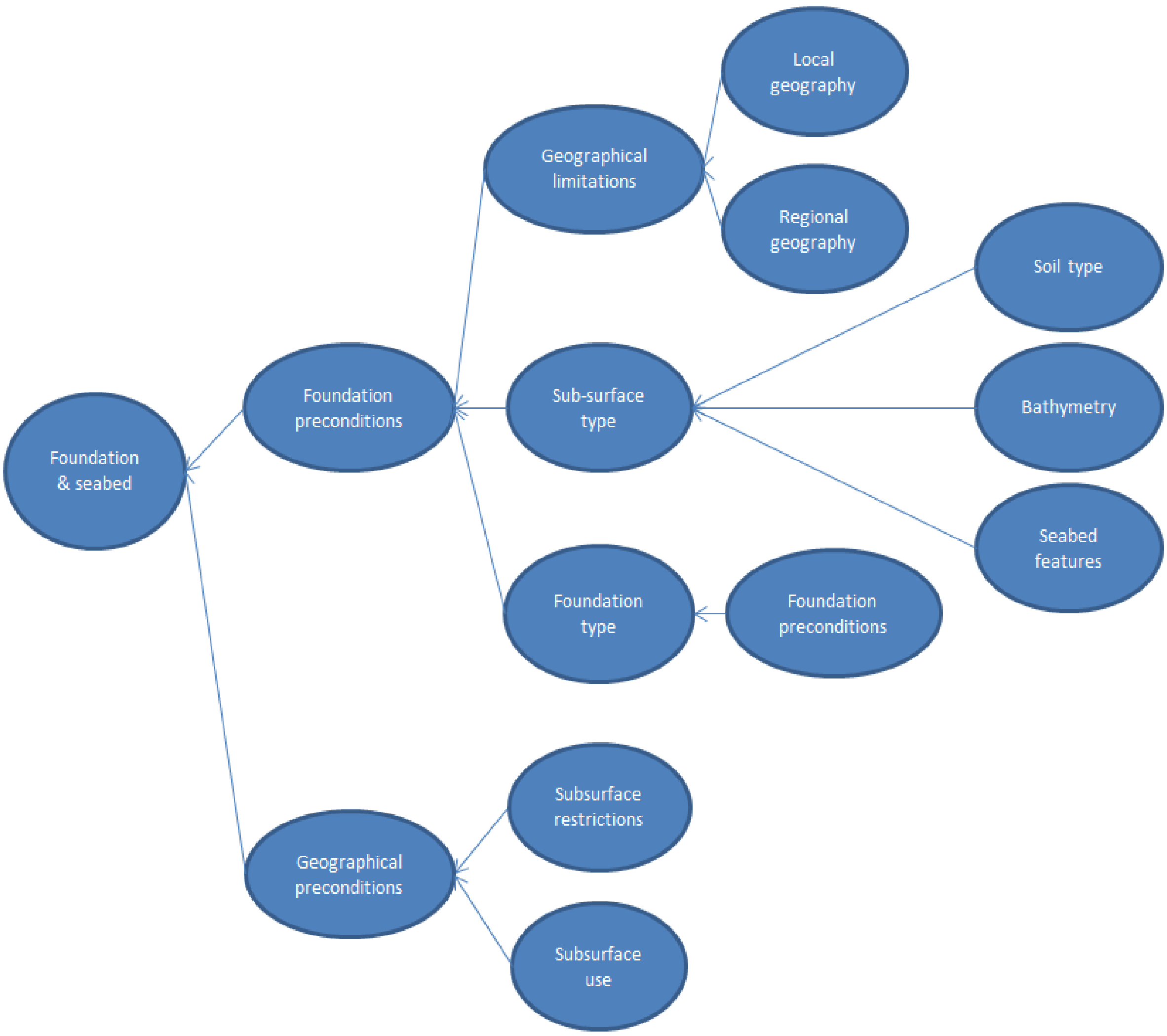

Figure 7: Foundation and seabed analysis model

The first split in the analysis model splits the foundation & seabed into foundation preconditions and geographical preconditions. The foundation preconditions consist of the combination between geographical limitations, sub-surface specifications and foundations suitability. Geographical preconditions focus on spatial restrictions in relation to subsurface use. The analysis of the foundation options is in close relation with the seabed and its preconditions and limitations. This is supported by Murakami et al. Based on the same approach, they model the suitability of locations for foundation design and then model the possibilities of offshore wind (Murakami, 2003).

Foundation preconditions

The categories foundation preconditions and geographical preconditions are the first split in the analysis model, figure 7. Multiple factors influence the suitability of a location for offshore wind foundations. The first set of influencing parameters are the geographical limitations. Geographical limitations directly influence the suitability of location for the placement of foundations. Through the factors: local- and regional geography the suitability of geographical locations is assessed. The local geography focuses on the lateral soil variations and the depth to the rock layers. The effects of finding less ideal soil layers in the direct location where the offshore wind turbine is placed are not go/no-go parameters but do influence the suitability of the location. Whereas local geology focuses on local issues, regional geology focuses on the seismic activity in the region. Areas with high seismic activities should be avoided. Assessing locational suitability based on geographical conditions is supported by the research of Kurt et al. They indicate that the impact of different geographical and geological characteristics and their effects on suitability is substantial and cannot be neglected in structural analysis (Kurt, 2014). The analysis point sub-surface type directly influences the suitability of certain locations and limits the options of different foundation types for offshore wind. Influences such as soil type, bathometry and seabed features are of high importance to the selection. To illustrate the diversity of subsea geological conditions the figure below has been added, figure 8.

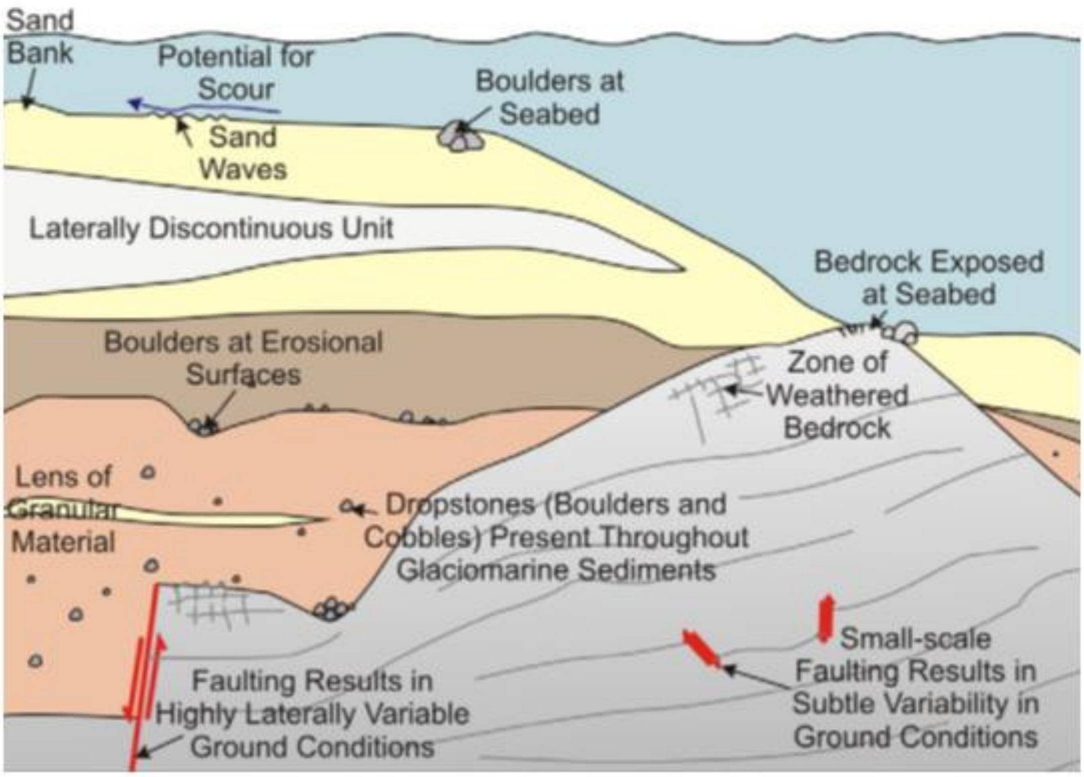

Figure 8: Representation of possible sub-sea conditions

For the analysis point foundation types, foundation preconditions are of main influence. The main influencing factors on foundation types are the turbine types, geographical limitation and sub-surface types including bathymetry sub surface use etc. figure 9, shows different foundation setups for offshore wind turbines. Eight types of foundations are shown schematically.

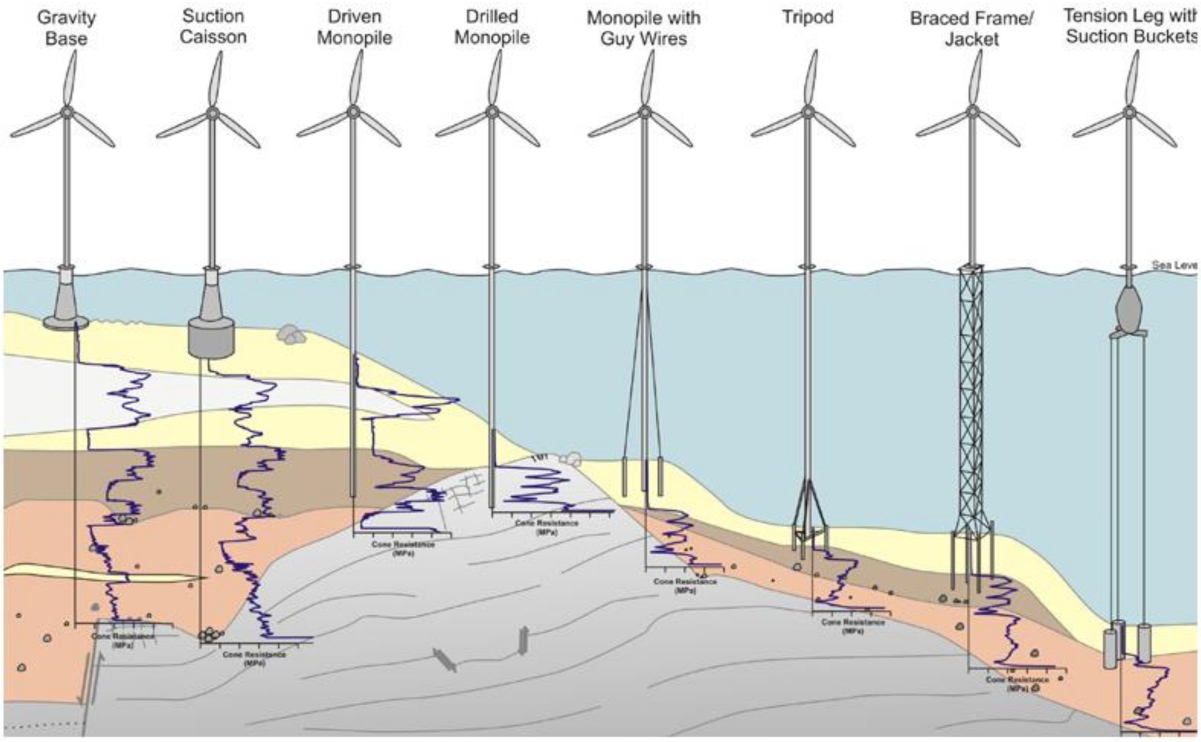

Figure 9: Representation of different foundation types with soil resistance function

For analysis of the possibility of foundation placement on different locations the model of Murakami et al. suggests an analysis strategy. This strategy evaluates location suitability based on: soil type, bathymetry and seabed features. The analysis strategy of S. Murakami at al. was the basis for the way the model incorporates the points connected to the factor sub-surface type. The analysis of locations based on location specific parameters is important because they influence the suitability of certain foundation types (Murakami, 2003). An easy example of a location specific parameter is the sea depth at the location. The figure above gives a good visual representation of the suitability of foundations based on depth to seabed. Gravity based foundations are, for example, not suitable for deep water locations. Further information on the foundation type selection can be found in appendix III.

Geographical preconditions

Geographical preconditions are mostly based on spatial restrictions set by the Dutch government. The “Rijksstructuurvisie Windenergie op zee” is the leading document indicating location functions (I&M, 2014). In the document the spatial planning of the Dutch offshore area is given. Multiple areas are given a specific function. An example of a usage function related to subsea use are locations indicated for the function of offshore gravel mining. These locations can, obviously, not be targeted for other functions due to their current function. Other examples of subsea area use are drill points for oil and gas and pipes and cables located in or on the seabed (I&M, 2014). Some functions have an additional restriction in relation to their function. A subsea cable or pipe, for example, has as direct relation that there is a spatial restriction of a 500 meter safety zone. In this safety zone no other activities can be planned. For the point: geographical preconditions subsurface restrictions and limitations are the main focus point.

5.1.2. Wind and ocean

The second category consists of the wind and ocean factors. The category is based on the factor selection of chapter 4, the wind and ocean. With these eight factors an analysis model is composed. The model consists of three topics and combines the factors with their relations. To complete the model eleven evaluation points were added. The evaluation points evaluate the linked actors on, for example, suitability. In total the model contains nineteen points. The analysis model containing the factors, relations and evaluation points is given in the figure below, figure 10.

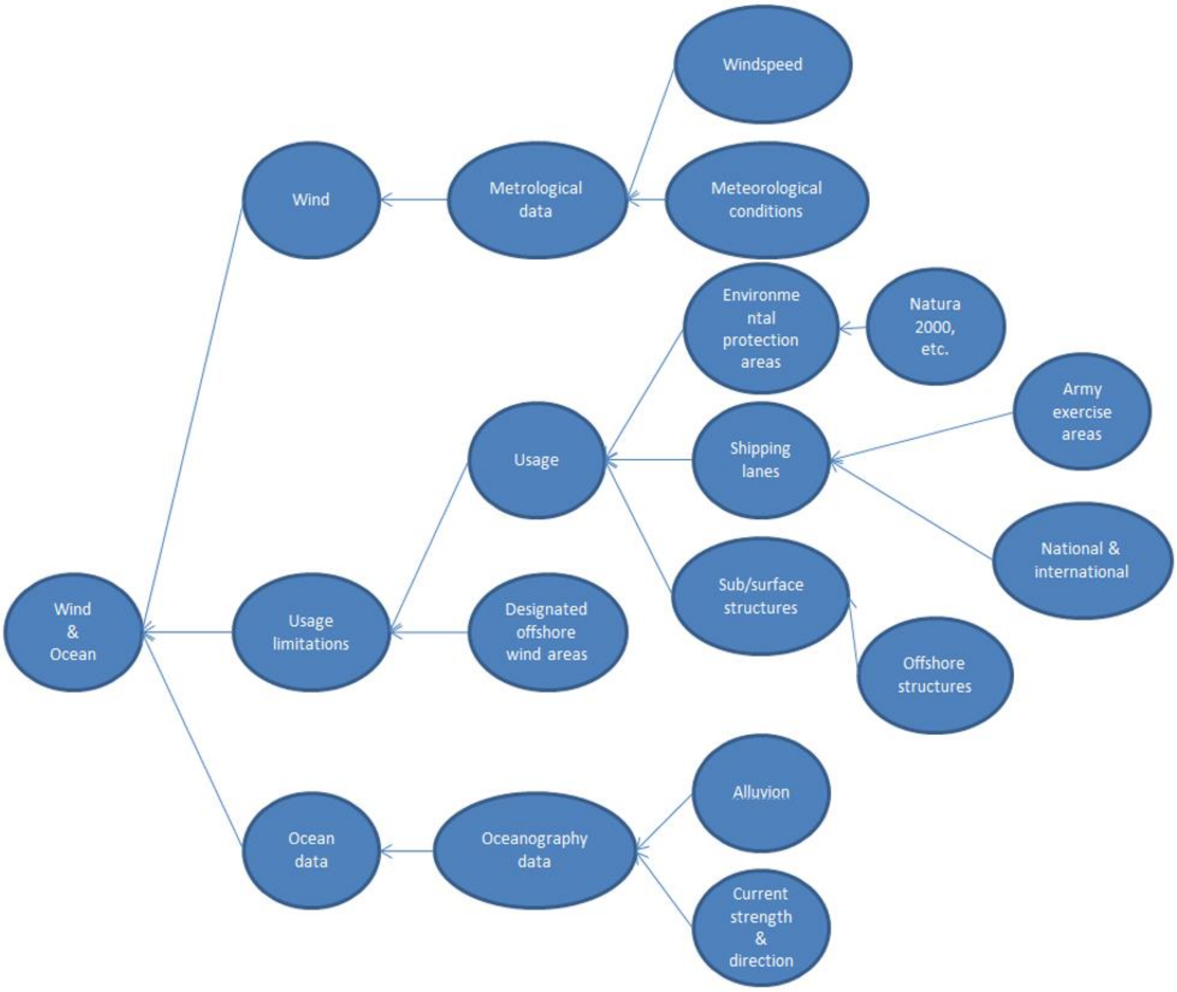

Figure 10: Analysis model wind and ocean

The first split in the wind & ocean model splits wind and ocean in the three topics; wind, usage limitations and ocean data. The split is based on the most common practice in scientific literature.

Wind

The first topic, wind, contains the influencing factors from a meteorological point of view. The main influencing factors are the wind conditions and meteorological conditions at the selected location. Although wind conditions on-site have a large influences on the type of turbine, power production etc. It was chosen to incorporate wind, and its factors/analysis points, at this point of the analysis structure. The reason for the incorporation at this point is the close relation in data acquisition with the oceanographic topic and because of the dominant influence of usage limitation on a site selection.

The importance of the factors, their relations and influence on the overall offshore wind suitability are well documented in current science. One of the more interesting studies covering this topic was the study of Lee et al. They focus on wind distribution potentials and power densities (Lee, 2013). In their study they analyse the interactions between the height of turbine hub, distribution and mean wind speed. In their conclusion they advise the use of the Weibull distribution for the probable density function of the wind and more interestingly they indicate the requirement of the direction of the wind as an analysis point. The mean wind direction is, according to them, of influence on the wind park design. Secondly they focus on the vertical wind profile at the selected site and stress the importance of accurate data. Especially data at the turbine hub height, is of importance according Lee et al. For the evaluation of wind speed at different heights they advise measurements or, if not available, standard formulas for the calculation of wind at different heights. Additionally they review the effects of meteorological conditions. Differences in air pressure has influence on the amount of potential power (Lee, 2013). The research from Lee et al. is supported by the research from Drechsel et al. Drechsel also looks into equations for the calculation of wind speed at different heights. In their results they advise a similar method for the analysis for wind speed (Drechsel, 2012). Another interesting research paper stressing the importance of meteorological data for the evaluation of the suitability of offshore wind is the model of Murakami et al. They designed a model which basis its analysis of a location for the construction of wind turbines on the meteorological suitability of the location instead of the more common energy generation capacity or seabed/foundation suitability (Murakami, 2003). Wind speed and calculations with wind speed are well documented in current research, but one indication keeps appearing throughout the studies. They all emphasize the importance of data accuracy for the analysis of the meteorological data.

Usage limitations

The second topic focuses on usage limitations in relation to spatial planning. The main topic is split in two. The first analysis point: usage is incorporated in order to deal with spatial usage limitation. Most spatial usage limitation are related to spatial planning of the government. For the Dutch offshore area the leading document is the so called: *"Rijksstuctuurvisie wind op zee"*. The document includes the Dutch spatial planning of the Dutch part of the North Sea. It appoints specific spatial functions to areas. Included spatial functions are environmental protection areas, navy exercise areas, shipping lanes and gravel mining areas. Additionally it includes the orientation areas for offshore wind. These selected orientation areas are the targeted areas for offshore wind. In these targeted areas offshore wind is the spatial function and development is possible (I&M, 2014). Next to spatial planning the "Rijksstructuurvisie" includes preconditions for both spatial and structural offshore activities (I&M, 2014). To emphasize the importance of a good location choice the research from Thomsen et al. can be quoted. In their research they compare sites for offshore wind development. They conclude that site suitability can have a major effect on energy production. According to them site selection has an influence of up to 50% on the energy production. (Thomsen, 2001). Although their analysis focuses on more than only spatial restrictions and influences, the importance of adequate site selection is clear. Although site selection, for the Dutch offshore area, is restricted to the areas with the spatial function of offshore wind, location evaluation will still be of importance. One of main reasons for the continuance of the importance of site selection is highlighted in the research of Kurt et al. They look into the influences of the positioning of wind turbines and the effects on fly pathways of birds (Kurt, 2014). In his research he indicates that a migration route of wildlife can be influenced by the construction of offshore wind turbines. Therefore the evaluation of the effects of turbine location on animal migration pathways should be investigated, possibly influencing the location of wind turbines. An other example of the continuance need for site selection analysis is the exclusion of some factors, for example location of pipes and cables and subsurface types, in the Dutch government site selection. The exclusion of factors in the initial location selection strengthens the need for a thorough evaluation in later stages of development (I&M, 2014).

Ocean data

The third topic focuses on the oceanic influence on offshore wind. This topic focuses specifically on oceanographic data. Influences such as scour and current erosion on offshore foundations are recent developments in this topic (Madariaga, 2012). Other influences such as alluvion, current strength and directions also have an influencing effect on windfarm setup. The impact of oceanographic influences on offshore wind is a factor that has to be evaluated. The study of J.M. Peeringa indicates that wave-current interaction should be taken into account for support structures design load calculations (Peeringa, 2014). Another point influencing offshore wind, though in a minor form, is the effect of wave influenced wind. Wind is distorted by the influence of the alluviation of the waves. The most common method of evaluation is the use of the terrain roughness variant for the offshore wind area. Although the influences of the waves on the wind is small. It is still interesting to see that even these small variables can have influences on the wind parameters (Kalvig, 2014). Again research focussing on these topics indicated that the accurate oceanographic data was of high importance.

5.1.3. Park and turbine

The third category focuses on the park and turbine factors of offshore wind. The ten previously selected factors from chapter 4 have been used as basis for the park and turbine analysis model. In order to compose the model the ten factors are evaluated on their relations. To complete the analysis model four evaluation points were added. In total these fourteen points are modelled into one analysis structure. The build-up of the model is based on the three categories of chapter 4. The analysis model is given in the figure below, figure 11.

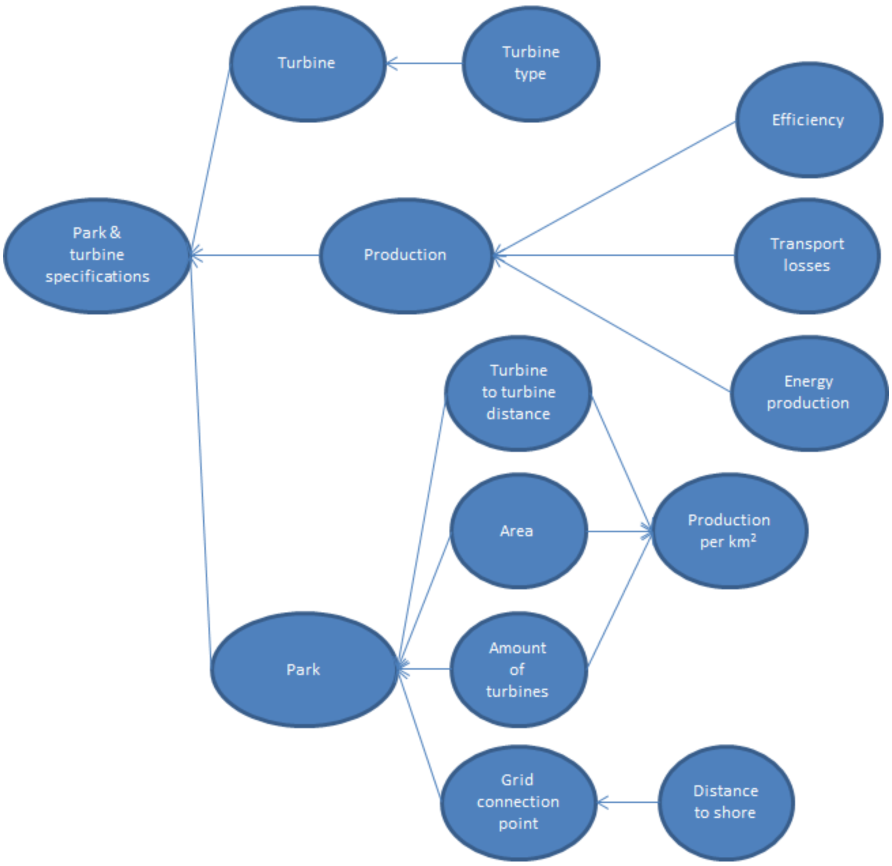

Figure 11: Park & turbine specifications

The analysis model given above contains the park & turbine specifications. The first split in the model splits the main evaluation point into three topics. The first topic is focussed on the turbine specifications, the second topic evaluates the production of offshore wind and the third topic evaluates the park setup and its influences.

Turbine

The evaluation point turbine focuses on the effects of different types of turbines. Although the influence of turbine types is rather obvious, the effects of wind turbine types have impacts throughout the model. An example of a different turbine setup is the difference between fixed or variable pitch turbines. Whereas variable speed turbines improve the dynamic behaviour in relation to fixed turbines, fixed pitch turbines decrease the stresses on the mechanical structure of the turbine (Saccomando, 2002). These kinds of differences have to be evaluated and assessed on preference and suitability. Parks located further offshore might prefer a turbine with less maintenance requirement, were parks located closer to shore might prefer turbines with higher output and a bit more maintenance requirement.

Production

The second topic evaluates the effects on the energy production of the offshore wind park. Overall the main influences are the efficiency, transport losses and the energy production. The production topic is closely related to the park setup and turbine type selection. To stress the importance of in situ design of offshore wind farms and evaluation of the park production factors the research of Fuglasang et al. can be cited. They evaluated the design of an existing offshore wind park consisting of 1.5 MW and 2.0 MW wind turbines. According to their research redesigning the spatial layout, energy transportation, turbine type and converter type, had an estimated potential energy production increase of 28% and had a decrease in costs of around 6% (Fuglsang, 2001). Overall they emphasize that production of an offshore wind park can be significantly improved through thorough evaluation. Another paper emphasizing the importance of the production evaluation is the research of Cherhouri et al. They focused on high-tech options for the production improvement of offshore wind (Chehouri, 2015). In the analysis model the close relation between energy production and park setup lead to the incorporation of the evaluation point production per km^2. Although the production per km^2 is significantly influenced by the production factors, the choice was made to incorporate the evaluation point at an extent of the park topic. This choice is based on the effect that energy per km^2 has on park setup. Calculation of production per km^2 are not an absolute necessity, but is related to a parameter set by the Dutch government and therefore important.

Park

The third topic evaluates the park setup of an offshore wind park. The topic is split into four factors, of which three factors influence one factor. The first factor, turbine to turbine distance, is of importance because it relates to the effects of wake forming. The effects of wake forming from one turbine to the next (turbine to turbine distance) are substantial according to Hassan et al. In their analysis they suggests that wake forming increases the extreme loads of the turbine with 50% and increases the fatigue damage rate with 17%. This suggests that minimizing wake effects increases the lifetime and decreases the maintenance requirements of windfarms (Hassan, 1988). Therefore this factor requires evaluation. In relation to the research of Hassan et al. Folkerts et al. suggests that severity of the effects of wake forming can vary. The main influencing factor on the severity of wake forming is the distance between wind turbines. A turbine to turbine distance of between 1.4 and 7.1 times the rotor diameter of the wind turbines has severe wake effects. The effects of wake forming on wind speed velocity deficits in the wake area vary between 12% and 56%, indicating significant wind speed loss (Folkerts, 2001). Dahlberg et al. further support the claim that wake effects are a serious factor. Their research

suggests that wind turbines operating in wake forms increase the blade load variations and increase fatigue. Evaluating offshore wind on turbine positioning can reduce wake effects (Dahlberg, 1992).
The factors area and the amount of turbine have, next to the production size effects, an extra beneficial effect. Having a large area with a large number of wind turbines decreases fluctuations in energy output. A large group of wind turbines has a smoothing effect on the short-term fluctuations in the overall energy output. The smoothing effected is caused the smaller effects individual wind turbines have on the total output. Individual wind turbine energy generation can be influenced by gusts of wind and/or variations of wind speed (Frotz, 1994). Having a more constant output of energy reduces fatigue in the energy converter stations and improves lifetime. Evaluating the grid connection method and distance to shore is of importance. Different setups of both can influence the transport losses and efficiency of the total system. According to Ackermann et al. the differences between DV and AC energy transportation from offshore to onshore should be evaluated based on the site-specific variables. Whereas differences in energy production fluctuations can be reduced more effectively by DV, AC has a preference over DV in shorter distance energy transportation (Ackermann, 2000). The evaluation point production per km^2 adds the option to evaluate the production of energy in relation to km^2. Energy production per km^2 is an important factor for the Dutch government. In their targets they pose a minimal energy generation requirement per km^2 of 3 MW (I&M, 2014).

5.1.4. Economics

Category 4, contains the economic factors. The twelve topics of the economic category are based on the four factors selected in chapter 4 added with eight evaluation points. To these factors eight evaluation points are added. Based on the factors, evaluation points and their relation the economics analysis model is composed. The analysis model is given in the figure below, figure 12.

Figure 12: Analysis model economics

The previous figure, figure 12, contains the analysis model of the economic category. The model is based on a cost/benefit approach. The principle of the applied cost/benefit approach can been seen at the first split. The two evaluation points costs and benefits make up the main topics.
In scientific research there is an emphasis on reducing costs for offshore wind. According to M. Arshad in 2013 levelised costs of offshore wind were about double that of onshore wind (Arshad, 2013). In order to reduce costs the Dutch government set cost reduction targets of up to 40% reduction of the initial costs. The timeframe for the realisation of the 40% reduction was the coming 10 years (Kamp, 2015). To illustrate the capital costs of offshore wind, the table of Islam et al. illustrating costs of offshore wind parks is added.

Table 7: capital costs of offshore wind farms

Wind farm	Capacity (MW)	Cost (million)		Cost/MW*	Year online
		Cost	Currency		
Kentish F.	90	105	GBP	2.14	2005
OWEZ	108	217	Euro	2.54	2006
Lillgrund	110	1800	SEK	2.38	2007
Robin Rigg	180	420	Euro	3.62	2008
Rhyl Flats	90	190	GBP	3.47	2009
Gunfleet S.	172	3900	DKK	3.75	2010

* Approximate cost in million USD/MW; exchange rates are chosen as respective years.

Costs
The first topic, costs, evaluates the three main cost factors. The first factor: operation and maintenance (O&M) is an influence for the entire lifetime of the wind park. O&M in itself is an important factor, according to We@sea O&M accounts for about 23% of the lifetime costs of offshore wind (We@sea, 2013). The analysis point of annual O&M costs is advised in the study of Astariz et al. They indicate that annual costs of O&M is an important factor in the financial evaluation of a wind park. O&M, due to its influence on costs, can jeopardize the financial viability of an offshore wind project. The influences caused by costs of downtime, repairs and above all the inevitable uncertainties. Need to be evaluated when considering investing in an offshore wind project (Astariz, 2015).
The second factor; construction, accounts for 58% of the offshore wind costs. Construction, in this estimation, consists of the wind turbine cost, foundation, tower and installation costs (We@sea, 2013). Building an offshore wind turbine, 5 MW, is, on average, priced around 18.5 Million USD. In relation, a wind turbine of the same power rating onshore is priced around 10 million USD (Islam, 2014). When looking into the costs of individual components of an offshore wind tower, costs vary. The tower of the turbine accounts for 26%. Whereas the generator and power converter account for 3% and 5%. The turbine blades account for 22% and the gearbox for 13% (Islam, 2014). The remaining 31% of the costs are distributed in small percentages over other factors, indications being transport, basic materials, etc. The installation of the constructed turbine poses additional costs. The development and engineering each account for approximately 10% of the cost. On-site construction account for about 40% up to 60% of the costs, depending on the location (Islam, 2014). The complexity and variation in cost price of wind turbines requires evaluation. Incorporation of this point can be found in the analysis model.
The third factor: electrical infrastructure looks into the costs related to the construction of the electricity grid/infrastructure. The electricity grid/infrastructure has to be constructed in order to connect the offshore wind park to the shore. The costs of connecting an offshore wind park to

the grid vary. The main influence on the costs is the location of the offshore wind park in relation to the gird connection point. Kurt et al. investigates this relation. In his research he hints that the main influences on connection costs are a combination between the connection cable, the location, the grid connection point and the connector (Kurt, 2014). Recent developments in Dutch politics tackle this problem for offshore development. The government appointed one operator for the entire Dutch offshore grid. This should reduce costs per kWh with 15 eurocents, resulting in a cost reduction of 30 billion in the coming 15 years (Kamp, 2015).
Getting a good insight into the costs of offshore wind is essential for the analysis of a location. The best way to visualize the costs of offshore wind, according to scientific literature, is through the costs of energy (Chehouri, 2015). The COE visualizes the cost for the production of one unit of energy. This way the costs that have to be made in order to produce one unit of energy are clearly visualized an incorporated in the representation figure.

Benefits
The second topic: benefits evaluates the financial benefits gained. The main gains for an offshore wind park originate through production and sales of sustainable energy. Secondary income such as: investments, subsidies and cost reductions influence the overall benefit. The influence of the main gain, energy sales, are rather clear. Considering the secondary benefits, the main influence is investments. Current research hardly covers the investments topic. One of the only papers addressing investment barriers was the research of Balks et al. According to Balks et al. private and public investors remain cautious to invest in offshore wind. They advise that governments focus on the mitigation of wind availability risk and focus on easing the possibilities for private and public sectors to invest in offshore wind (Balks, 2014). Although this paper is focused on the German economic sector, the same goes for the Dutch investment climate. Risks related to investing in offshore wind are significant. One of the main reasons for this is the wind prediction uncertainty. Wind speed and especially wind power predictions influence the production capacity of a park and indirectly the will to invest. Improving reliability of these prediction models would reduce the risks and increase the so called "will to invest" (Balks, 2014).

5.2.Factor preconditions

This sub-chapter contains the preconditions related to the selected factors. Factor preconditions investigate the preconditions set to each factor. Factor preconditions can be in form of a fixed value (set parameters) or in the form of a range of possibilities (variable parameters/ranged area parameters). With the preconditions attributed to the factors the analysis method will become more functional.

5.2.1. Set parameters

Set parameters are parameters that have to be met. If a parameter is not met or cannot be met. The factor would, on itself, prevent the possibility of offshore wind at that location. Therefore mapping and adding the set parameters related to factors incorporated in the analysis method was considered of high importance. The factors which are evaluated based on a set parameter are given in the table 8. In total thirteen factors were identified as factors with set parameters.

Table 8: Factors with set parameters
Sources: **(I&M, 2013; I&M, 2014; Arshad, 2013; Alati, 2015; Fuglsang, 2001; Zaaijer, 2009)**

Factor / analysis point	Set / variable	Parameter
Foundation preconditions	Set	Foundation types are limited to the foundation type specifications. For example: depth, sea bed anchorage method.
Subsurface structures	Set	Subsurface structures and its location influence suitability. Design adaptation might be required.

Subsurface use	Set	Locations selected for a specific use function cannot overlap.
Environmental protections	Set	Locations selected as an environmental protection area cannot overlap with offshore wind as of now. This is currently being reviewed.
Shipping areas	Set	Locations selected for a specific use function cannot overlap. Set distance to shipping areas has to be taken into account.
Indicated offshore wind areas	Set	Only areas selected for the development of offshore wind can be assessed for development.
Exploitation areas	Set	Locations selected for a specific usage function cannot overlap.
Grid connection point	Set	Grid point connections are set. Locations are selected by TENNET the national operator of the offshore grid.
Foundation preconditions	Set	On-site evaluation selects the most suitable foundation type. Influencing parameters are: costs, depth, climate conditions, wind speed and planned wind turbine load.
Geographical limitations	Set	Location suitability is based on the presence of boulders, subsurface use, subsurface structures, wreck and archaeological value.
Sub-surface type	Set	No direct major consequence is related to sub-surface type. The sub-surface composition does influence suitability and might require design adaptation.
Geographical preconditions	Set	Location of high seismic activity should be avoided.
Usage limitations	Set	Overlapping usage is in most conditions not possible.

The table above contains the factors with set preconditions. For these factors the most pressing preconditions are selected and displayed. Although most of the preconditions are clear some require further explanation.
For the *subsurface structures* the preconditions are related to the specific subsurface structure. The parameters related to individual subsurface structures are not presented in the table above but can be found in table 9.
The *sub-surface type* influences the suitability of the subsurface for the construction of the park. An example of a less ideal subsurface is a subsurface profile that has a steep slope or highly inconsistent soil profile. An inconsistent soil profile has effect on the suitably of the soil for the construction of foundations etc. In its most extreme form the sub-surface type might make the construction of certain types of foundations difficult (Kay, 2009).
For the geographical limitation goes that the locations are evaluated based on the presence of boulders, wrecks, military graves, etc. If one of these is present at the location the location has to be re-evaluated. In most cases it remains possible to develop offshore wind at such a location but additional measures have to be taken in order to ensure the safety of the wind farm or the wreck/archaeological site. (I&M, 2014).
For usage limitation counts that a location that has been given a specific usage function. Cannot be used for a different function. Although this is true, currently the possibility to allow recreational sailing, aquaculture and some forms of fishing in offshore wind farms is under evaluation, indicating possible future possibilities of combinations of usage functions (I&M, 2013).
In addition some factor preconditions are less pressing issues and are therefore not directly attributed to a specific factor in the table 8. Although these preconditions are not incorporated in the table they are still of importance. These preconditions are displayed in the table 9 below.

Table 9: Unclassified preconditions
Sources: (I&M, 2014; I&M, 2013)

Topic	Precondition
Safety zones oil/gas	- 5 Nautical miles around offshore platforms with helicopter platform - 500 meter around normal offshore platforms
Safety zones shipping lanes	2 Nautical miles distance to international shipping lanes, anchorage areas and nationally regulated clearways
Safety zones pipes/cables	500 meter safety zone around pipes/cables
Exclusion zones	- Locations of high archaeological value (wrecks, prehistoric civilizations locations etc.) - Sand mining areas - 12-mile zone
Environmental protection	Based on the locations ecological structure mitigating measures, preventing environmental damage, have to be implemented.

Table 9 above contains parameters that cannot be accounted to a direct factor but are of significant influence on location suitability for offshore wind. All the preconditions are fixed and have to be held into account. The first additional preconditions concern spatial planning. The spatial preconditions related to safety zones and exclusion areas are of importance to offshore wind. They are however not of main concern because the preselected offshore area in the Dutch offshore area, already hold some of these preconditions in account (I&M, 2014).
For the environmental protection precondition some additional explanation is required. For the preconditions goes that any location selected for the development of offshore wind is evaluated on environmental impact. During this investigation the effects of construction and exploitation on the local ecological structure is evaluated. Mitigating measures have to be taken in order to prevent damage on the local ecology. The type of mitigation measures is based on the structure of the local ecological structure. The main goal of the environmental protection preconditions is to prevent direct and indirect negative effects for the local ecology. For the Dutch sector the document: *"ecologie en cumulatie",* currently being in development, will be the guiding document. This document will serve as assessment structure for the local ecology (I&M, 2014).

5.2.2. Variable parameters & ranged area parameters

Variable parameters factors and ranged area factors are factors that have a variable parameter or a parameter that has a range of acceptability. The variable factors can have a different requirement when evaluated at different locations. For both kinds of factors goes that if the requirements are not met the suitability of the location for offshore wind has to be reconsidered. Table 10 contains the variable factors and their parameters.

Table 10: Variable parameters & ranged area parameters
Source: (Ackermann, 2000; Kamp, 2015; Islam, 2014; I&M, 2014; Berkhuizen, 1988; Byrne, 2003; Chehouri, 2015; Min. V&W, 2009; Carswell, 2015)

Factor / analysis point	Set / variable	Parameter
Soil profile	Variable	Evaluates based on soil types and soil composition. Higher consistency is better.
Local geology	Variable	Soil layer composition has to be in line with foundation preconditions
Regional geology	Variable	Avoid lose sands and active seismic areas.
Bathymetry	Variable	Depth to seabed has to be in line with foundation preconditions. Design adaptation is possible.
Seabed features	Variable	Areas with boulders should be avoided. The presence of other seabed features can be overcome with design adaptation.
Wind parameter	Variable	Maximum efficiency of offshore wind is on average at a wind speed of around 11 m/s 16 m/s.

Meteorological conditions	Variable	Average wind speed, rainfall, sun intensity etc. have to be evaluated based on rig preconditions.
Wave parameters	Variable	Wave height has to be in line with foundation and rig preconditions. Design adaptation is possible.
Current parameters	Variable	Current parameters have to be assessed in order to evaluate lifetime and construction influences. Must be in line with foundation and rig preconditions.
Amount of turbines	Variable	The total amount of turbines has to have a total energy production of at least 100 MW.
Turbine to turbine distance	Variable	Standard turbine to turbine distance is based on turbine blade length. 4*diameter of the turbine blade wide and 8*diameter of the turbine blade long is set as minimal standard.
Park area	Variable	The minimum park area has to be at least 80 km^2. In order to prevent fragmentation of offshore wind park location.
Distance to shore	Variable	The distance to shore is a direct consequence of the park location choice. Distance to shore and distance to grid connection point has to be evaluated separately.
Wake forming	Variable	Wake forming occurs when turbine to turbine distance is less optimal. Wake forming might require design adaptations.
Turbine type	Variable	Turbine type is preference and situational design based.
Efficiency	Variable	Efficiency is dependent on park and turbine specifications.
Transportation loss	Variable	Transport loss has to be evaluated based on the relation between distance of transport, transport type and loss.
Energy production	Variable	The minimal energy production of the park has to be 100 MW. Higher production is based on preference and suitability.
Construction	Variable	Construction counts on average for 40% to 60% of total costs. Dependable on location, materials, foundation type etc. design adaptation should always evaluate the reduction of construction cost.
Operations and maintenance	Variable	On average O&M accounts for 23% of the lifetime costs. Lower O&M costs are a target to strive for.
Electrical infrastructure	Variable	Electrical infrastructure is in control of TENNET. No parameter can be connected to this topic.
Energy profits	Variable	No direct parameter can be connected to this point. Only parameter is the cost of energy reduction of 40% in the next 10 year.
Foundation type	Variable	Based on previous factors the type of foundation for the given location is selected. Different situations require different foundation. No direct parameter can be set to this topic.
Ocean data	Variable	Location with high alluvation has to be avoided. Design adaptations are possible for most oceanographic variations.
Turbine	Variable	Preconditions vary per turbine type.
Production	Variable	Wind park has to have a minimal production of 100 MW.
Costs	Variable	CoE (Cost of Energy) 15 cents per kWh in 2014. Targeted CoE in 2024 9 cents per kWh.
Benefits	Variable	For benefits no direct parameter can be set. This depends on the developer of the offshore park. As a basis a positive return on investment can be used.

In the table added above the variable factors with their parameters can be found. Most of the factors are self-explaining. Some factors are not that clear or cannot be allocated to a direct parameter, these factors require further explanation. The first parameter that requires explanation is the parameter related to the seabed features factor. This parameter indicates that the presence of boulders or other seabed features should be indicated as a complication. Although this is true the presence of problematic seabed features does not make the location completely unsuitable for offshore wind. In most cases measures can be taken or design adaptations can be made to overcome the complication (Murakami, 2003).
For the claim of an optimal performance of a wind turbine at 11 m/s to 16 m/s a scientific base

is required. On average the maximum efficiency of offshore wind turbines is reached at a wind speed between 11 m/s and 16 m/s (Ackermann, 2000; Ashuri, 2013). According to their research the exact optimum depends on the specific wind turbine but on average areas with this wind speed should be targeted according to their research. Areas with higher or lower wind speed can still be selected but locations with an average wind speed that fits in the ranged area should according to Ackerman et al. and Ashuri et al. be preferred.
For the factors: amount of turbines, production and energy production a fixed parameter is coupled to a variable factor. This is due to policy of the Dutch government. The government will only allow offshore wind farms with a minimal production capacity of 100 MW (I&M, 2014). The goal of this policy is to prevent chaotic dispersing of numerous small offshore wind farm throughout the Dutch offshore area. With this more centralized generation of offshore wind energy, additional benefits such as costs reduction and a more constant energy output because of the reduced influence of gust effects are also exploited (Frotz, 1994). The second ambition of the Dutch government is the generation of 3 MW of production per km^2 of park area (I&M, 2014). This ambition is strong but not binding. Park construction will still be possible if generation does not make the 3 MW per km^2 quota, but does meet the 100MW energy production minimum.
The turbine to turbine distance parameter is based on common practice. Because the square build-up of the park layout is common practice it is set as a parameter. But in current research different park layout setups are one of the main topics of development, therefore the parameter might in the near future be altered (Raadal, 2014; Byrne, 2003). Alternative setups of park layout have promising effects on both energy output and on decreasing effects on turbine loads. The most significant gains are found in the reduction of wake effects. In addition the ability to select the location of the turbines based on the most ideal locations for the foundation of the turbine are advantages (Raadal, 2014). Therefor the parameter gives the advice to analyse the park based on setup and layout. But as basic parameter the common practise is used.
The parameter set to the park area is a variable and soft parameter. A wind park can have a smaller area than 80 km^2. As long as it makes the minimal production quota of 100 MW (I&M, 2014). On average wind park areas of 80 km^2 and larger are more common. Mostly due to possibility of maintaining a larger turbine to turbine distance and thereby decreasing wake effects and the advantage of having a more constant energy output because of scale of a larger park. For example a wind farm with more turbines decreases the relative O&M costs per turbine (Astariz, 2015).
For the distance to shore factor no direct parameter could be set. The distance to shore can be evaluated based on two functions. One function could be: the distance a ship has to sail before it reaches the offshore wind park. In this case the factor would focus on park to harbour distance. The second function could be: the distance from park to the energy supply point. In that case the factor would focus on the distance that energy would have to be transported before it could be applied. In both cases the shorter distance to “shore” the better. Shorter shipping times would reduce costs for O&M and shorter distance of energy transportation would reduce the energy loss through transportation.
For the electrical infrastructure factor no parameter exists. The non-existence of a parameter for the electrical infrastructure is a result of the integral management of the offshore electricity grid through one grid operator. For the construction operation and management of the offshore grid TENNET is selected by the Dutch government (Kamp, 2015). The selection of one integral operator of the offshore grid, according to Kamp, is based the potential financial savings. The total estimated savings is 3 billion euros over a timespan of 15 years (Kamp, 2015).
For the cost factor the related parameter is not a fixed parameter but it is a target for the near future. The target, reducing the cost of energy with 40% from 15 euro cents a kWh to 9 euro cents a kWh, is set by the Dutch government. This targeted reduction makes offshore wind energy more competitive with onshore and conventional produced energy (Kamp, 2015).

6. Dataset identification

Whereas the research in the previous chapter focused on the design of the analysis structure for the evaluation of locations for offshore wind, this chapter investigates the data input. When investigating locations for the possibilities of offshore development the data availability varies. Therefore mapping the required data for analysis is the next logical step in the research.
To stress the importance of accurate data mapping and prediction models the research of Billinton et al. is highlighted. In their study on wind energy converter reliability and performance, they indicate that the main influencing factor on the reliability of the wind energy converters is dependent on the onsite wind conditions. Most of the energy generation predictions that were out of balance with the actual onsite wind conditions were based on datasets that proved to be inaccurate or inadequate for the analysis (Billinton, 2004). Furthermore they indicate that the reliability of the estimation of wind conditions onsite is vital for the selection of the most suitable wind energy converter systems. In order to make a reliable prediction, data reliability and data accuracy are of main importance. If the dataset is unreliable, the prediction is unreliable as well. Therefore not only the analysis of data sets but also the indication of the requirements of the datasets are of importance.
The complete list of datasets required for an optimal analysis based on the analysis method designed in chapter 5 is given in table 11 below. In total twelve datasets are required. These datasets should contain information on the factors/analysis points linked to the dataset as given in the table below. If the dataset includes data on all the points the data set is complete.

Table 11: Complete list of datasets
Sources: (Billinton, 2004; Byrne, 2003; Berkhuizen, 1988; Tande, 2004; Balks, 2014; Mitrof, 1983; Zaaijer, 2009; Carswell, 2015)

Dataset	Factors/analysis points
Bathymetry	Bathymetry
Seabed profile	Seabed features, Subsurface type, subsurface structures, subsurface use
Sub-soil profile	Soil profile, regional geology, local geology
Geographic profile	Geographical preconditions, usage limitations, geographical limitations, indicated offshore wind areas
Exclusion areas	Safety zones oil/gas, safety zones shipping lanes, safety zones pipes/cables, exclusion zones, shipping areas, exploitation areas
Meteorological profile	Wind parameter, meteorological conditions, wave parameters
Oceanographic profile	Ocean data, environmental protection, current parameter
Wind turbine profile	Turbine type, foundation type, foundation preconditions, turbine
Park profile	Amount of turbines, wake forming, operations and maintenance, construction, electrical infrastructure
Location profile	Distance to shore, grid connection point, park area, turbine to turbine distance
Production profile	Efficiency, transportation loss, energy production, energy profits, production
Financial profile	Costs, benefits

With all the factors/analysis points grouped per dataset the datasets can be evaluated on completeness. Data completeness has often been a problem, even for studies focusing on data extrapolation in areas with low data availability Examples of studies having difficulties with data quality and availability are the studies of Copping et al. In their study they focus on the environmental effects of an offshore wind farm and have complication with data assembly due the availability of observatory and experimental data (Copping, 2014). Another example is the study of Hasager et al. They focus their research on the development of a method for the analysis of locations where data is lacking or were data is of such a low quality that it is not useable. In their method they evaluate the reliability of prediction models predicting onsite climatology data based on models, using among other sources satellite data (Hasager, 2015). Next to these studies, the points of interest data quality and data uniformity which have been presented in this research also indicate that data reliability is of importance. This double indication only strengthen the value of the evaluation of data and datasets.

7. Data assessment

In this chapter the required datasets for an optimal analysis are evaluated. If the datasets meet the set parameters indicated in sub-chapter 7.1 the dataset can be quantified as relevant. In sub-chapter 7.2 a value aggregation method is designed to aggregate value to the relevant datasets. With the sum of the relative value of the relevant datasets the data availability can be indicated.

7.1. Parameters per dataset

In chapter 6 the required datasets for an optimal analysis have been identified. Based on scientific literature preconditions are set to the datasets in the form of parameters. The importance of data validation can be seen throughout scientific literature. A clear example of the importance of data validation is indicated in the research of Soukissian et al. In their research they stress the effects of different data sources on evaluation outputs. Through reviewing multiple types of data gathering, they found that data quality varies rather extensively. The most extensive variation in data quality was related to the relevance, out of date or up to date, and data resolution, m/s or km/h of the data (Soukissian, 2014). Further emphasizing on the importance of data quality assessment is the research of Fitzwater et al. They research the load effects on a wind turbine using multiple different extrapolation models. Additionally they analyse the effect of statistical uncertainties in relation to the type of data used in their extrapolation models. In their conclusion they indicated that the importance of reliable data is significant and has to be kept in mind when researching with statistical uncertainties. Furthermore it was interesting to see how the data they acquired with the different extrapolation models varied significantly. When looking at the impact of these variations they indicate that the quality of the extrapolated data had an impact when evaluating the load effects (Fitzwater, 2001). Keeping indications like those given in the research of Frizwater et al. in mind, the importance of the use of reliable data is evident. To incorporate data reliability as much as possible in the analysis method, parameters are set to the individual data sets. The preconditions can be found in table 13 below.

Table 12: Dataset preconditions
Sources: (Lee, 2013; Fitzwater, 2001; Soukissian, 2014; Carswell, 2015)

Dataset	Data preconditions
Bathymetry	Has to be as recent as possible, data older than 5 years has to be updated
Seabed profile	Has to be as recent as possible, data older than 5 years has to be updated
Sub-soil profile	Has to be as recent as possible, data older than 5 years has to be updated
Geographic profile	Data has to be up-to-date and re-analysis is advised if data is older than 1 year
Exclusion areas	Data has to be up-to-date and re-analysis is advised if data is older than 1 year
Meteorological profile	Measurements have to be measured for at least 1 full year, measured during all seasons
Oceanographic profile	Measurements have to be measured for at least 1 full year, measured during all seasons
Wind turbine profile	Data is developed by the developer. Preconditions cannot be set. Factor and analysis points preconditions have to be met.
Park profile	Data is developed by the developer. Preconditions cannot be set. Factor and analysis points preconditions have to be met.
Location profile	Data is developed by the developer. Preconditions cannot be set. Factor and analysis points preconditions have to be met.
Production profile	Data is developed by the developer. Preconditions cannot be set. Factor and analysis points preconditions have to be met.

Financial profile	Preferably the outcome has to be combined with a *p*-value (probability value)

In table 13 the preconditions set to datasets can be found. Although the preconditions set to the datasets are not that specific, more specific preconditions are not present in scientific literature. Data availability was one of the main influencing factors on data selection in current research. Often the researcher did not have an extensive amount of data available for their research (Angelakoglou, 2013; Tsu-Ming, 2013). A few research projects are even focussed on methods to extrapolate data to a location where no data was available at all (Hasager, 2015; Jiménrx, 2015). Because of the meagre data availability, data selection was often not that specific or reliable. Even though most studies did not set clear preconditions to the input data they often did highlight inconstancies, preferences or improvements on their data input. Evaluating data quality based on these suggested improvements and set preconditions resulted in the best data preconditions that could be based on scientific literature.

For the first three datasets, bathymetry, seabed profile and soil-profile, the preconditions set to the data was that the data has to be as recent as possible and data older than 5 years has to be updated. According to, among others, Carswell et al. data on the sub-sea older than 5 years has a lowered reliability and was advised to be updated (Carswell, 2015). The lowered reliability can for example be caused by the effects of currents eroding the seabed, geophysical or human activities. The combination between naturally occurring phenomena and the effects of human activities on the seabed can be extensive (Carswell, 2015). As a result the precondition: "the data has to be as recent as possible and data older than 5 years has to be updated" was set to the dataset.

For the geographical profile and the exclusion areas the precondition set to the datasets is that the datasets cannot be older than one year. The effects on the geographical profiles and exclusion areas are mostly political and can change in a rather short timeframe. Therefore the data in fact has to be as up-to-date as possible. In order to guarantee the reliability as much as possible and at the same time set realistic parameters, the selected precondition set to the datasets became: data has to be up to date and re-analysis is advised if data is older than 1 year. In appendix IV an example of out of date legislative data can be found. This example was provided by the "national georegister" on 20th of April 2015 which should be a reliable source. Unfortunately the example shows a planned windfarm at a location that is no longer possible due to policy change. Although the change is already final and in effect the data still indicates the windfarm as under consideration. This delay in data updating is a clear example of why data of this dataset should be as up-to-date as possible. Other effects of policy or spatial regulation on, for example, sand mining areas or military exercise areas and their related safety areas on the development of offshore wind is extensive. Location suitability for offshore development is highly dependent on a correct indication of the functional and safety areas. If these area indications are incorrect the effect on the reliably of the analysis is considerable, further emphasising the importance of the posed dataset precondition.

For the meteorological and oceanographic profile datasets the preconditions set indicates that the data has to be recorded for at least one full year. This precondition is related to the influences of seasonal effects on the measured data. A clear example of seasonal effects can be seen in the research of Lee et al. In their research they evaluate an offshore wind site in Korea. At this site they analyse the effects seasons have on the average wind speed. For the chosen site the difference between the average wind speed in summer and winter is around 0.5 m/s (Lee,

2013). An incorrect estimation of wind conditions onsite due to incorrectly measuring data can have significant effects on energy production estimated in the analysis. The same goes for seasonal effects on the other data points incorporated in the dataset. Therefore the precondition: measurements have to be measured for at least 1 full year, measured during all seasons, was set.
The wind turbine, park, location and production profile datasets are datasets that are differently sourced. Their profiles are designed based on input data from the other datasets or are a result of an analysis or preference. Therefore the decision has been made not to set specific preconditions to these datasets. The preconditions that could be set would not have an added value. Mapping the demands/preferences by developers etc. would result in questionable and refutable results.
To a certain degree the financial profile is also dependant on the preferences of the investors. The investor will have specific investment criteria. For example criteria based on NPV or PBP could be set to the project in order to assess its suitability for the investor. Because of differences in investment criteria of the investors no specific parameter could be set. Although no specific parameter could be set, an alternative parameter was chosen. The set parameter suggests the incorporation of a *p*-value indicating the probability of the costs/benefit value. By way of this probability value the reliability of the estimation can be indicated. Indicating the probability to which extent it is to be expected that the posed financial prognoses will be met will have an added value for the investors (Madariaga, 2012).

7.2. Value aggregation method

Where the previous sub-chapter focused on the assessment of the reliability of the individual data points, this sub-chapter focusses on the identification of data completeness. As indicated previously, data quality is an important topic for offshore wind. When performing the analysis designed in this research, the required data or part of the required data might be missing or is of bad quality. In order to cope with data problems, the relative value of the individual factors/analysis points to the overall analysis has been quantified. With the aggregation of relative value to the individual points and the assessment of its data, the quality of the data used as base for the analysis can be assessed and indicated. With this approach two different locations with different data availability, quality and outcome can be assessed on their source data. If for example location X has significantly more data available then location Y, the outcome of the analysis at location Y can still be more positive in terms of energy production then the outcome at location X. Problems with available data like this can cause wrong assumptions. With the addition of the data assessment presented in this research, the data used as basis for the analysis can be analysed and indicated. With the addition of an indication to which extent data was available at the analysed location. The analysis would put things back in perspective and the evaluation of different locations with different extent of data would again be possible.
In table 12 the datasets and their incorporated factors and analysis points are given. The individual factors/analysis points have been given a value from 1 to 3. This value indicates their relative importance to the overall analysis. The higher the value the higher the number linked to the factor/analysis point.

Table 13: Value aggregation to datasets and dataset content
(Billinton, 2004; Byrne, 2003; Berkhuizen, 1988; Tande, 2004; Balks, 2014; Mitrof, 1983; Zaaijer, 2009; Carswell, 2015; Theunissen, 2014; Lee, 2013)

Dataset	Factors/analysis points					
Bathymetry	*Bathymetry*					
2	**2**					
Seabed profile	*Seabed features*	*Subsurface type*	*Subsurface structures*	*Subsurface use*		
3	**3**	**2**	**3**	**3**		
Sub-soil profile	*Soil profile*	*Regional geology*	*Local geology*			
1	**1**	**1**	**1**			
Geographic profile	*Geographical preconditions*	*Usage limitations*	*Geographical limitations*	*Indicated offshore wind areas*		
3	**1**	**2**	**2**	**3**		
Exclusion areas	*Safety zones oil/gas*	*Safety zones shipping lanes*	*Safety zones pipes/cables*	*Exclusion zones*	*Shipping areas*	*Exploitation areas*
1	**1**	**1**	**1**	**1**	**1**	**1**
Meteorological profile	*Wind parameter*	*Meteorological conditions*	*Wave parameters*			
3	**3**	**2**	**1**			
Oceanographic profile	*Ocean data*	*Environmental protection*	*Current parameters*			
2	**2**	**2**	**1**			
Wind turbine profile	*Turbine type*	*Foundation type*	*Foundation preconditions*	*Turbine*		
2	**2**	**1**	**1**	**2**		
Park profile	*Amount of turbines*	*Wake forming*	*Operations and maintenance*	*Construction*	*Electrical infrastructure*	
2	**2**	**1**	**1**	**1**	**1**	
Location profile	*Distance to shore*	*Grid connection point*	*Park area*	*Turbine to turbine distance*		
2	**1**	**1**	**2**	**1**		
Production profile	*Efficiency*	*Transportation loss*	*Energy production*	*Energy profits*	*Production*	
2	**2**	**1**	**2**	**1**	**2**	
Financial profile	*Costs*	*Benefits*				
1	**1**	**1**				

With the table above it becomes possible to benchmark two, or more, different analysis outcomes based on their data quality. Additionally the method makes it possible to assess different locations based on the data available. When a location is selected and data collection has been completed, the available data can be analysed based on the table above.
The height of the summed up total of the numbers related to the available and accurate dataset in an analysis indicates the quality of the data available for the analysis. Effectively, the higher the summed up total the better the data availability. Indicating to which extent data is available for the analysis is of value, because it is to be expected that in most cases the analysis will not have all the data required to perform an optimal analysis. Lastly the indication of data availability is in line with the point of interest data quality.

8. Validation

In order to validate the relevance and completeness of the analysis, this chapter recaps on the three points of interest highlighted in chapter 3: actor analysis.

8.1. Quality of data

The point of interest: quality of data emphasizes the importance of the quality of data used for the analysis structure. This point of interest is woven through chapter 6 and 7. The influence of the point of interest can clearly been seen in chapter 6. Chapter 6 evaluates the data input and sets parameters to the datasets required for the analysis. The research into these parameters is a direct consequence of the point of interest: quality of data. In chapter 7 this point of interest is also of influence. This chapter examines which data initially is required to perform the analysis and evaluates how they form datasets. Indicating the composition of the individual data points in the datasets has as its goal to give a clear insight into the required data and indirectly indicate the quality of the data used for the analysis. This indication makes it possible to identify data requirements and benchmark data quality between different locations or studies. A clear example of setting data quality standards is the value aggradation to the factors and analysis point of the model, sub-chapter 7.2. Benchmarking two analysed locations with the value aggradation approach gives an insight into the reliability and completeness of the datasets used in the initial evaluation. Effectively this insight gives insight into the data quality of the analysis, further strengthening the incorporation of the point of interest.

8.2.Uniformity

The point of interest: uniformity focuses on the uniformity of data. This point of interest is incorporated in two different methods. The first method of incorporation is in the form of a factor and analysis point in the factor selection chapter, chapter 4. In this chapter, the point of interest is of direct influence on the factors subsurface use and usage limitations. Both factors look into the usage of an area and have as factor preconditions the parameter that no overlap can be present. Through the evaluation of uniformity based on the factor incorporation in the analysis model the initial overlapping sites are identified in the analysis itself. In order to make sure that the input data does contain bad uniformity of data, the point of interest is incorporation in a second method. The second method of incorporation is in the form of a parameter in the data assessment chapter, chapter 7. In the data assessment chapter, the incorporation of the point of interest is most prominently present in the parameters set to the datasets, geographical profile and exclusion zones. The parameters set to these datasets indicate re-evaluation of the input data if the data is older than one year. Through the incorporation of these methods lacking data uniformity was countered as much as possible.

8.3. Spatial overlap/pressure

The point of interest: spatial overlap/pressure is incorporated in the chapters 4 and 5. In the factor selection chapter, chapter 4, this point of interest is related to all the factors influencing spatial positioning. The clearest factors influenced by this point of interest are: sub-surface structures, shipping areas, windfarm area and geology. A clear example of the importance of the effects of spatial overlap/pressure can be found in the assessment methodology design chapter, chapter 5. In the assessment methodology design, spatial overlap is incorporated as a direct point of analysis in the model. Also the analysis point geographical preconditions is a direct effect of the point of interest. Through the incorporation of these factors, the point of interest spatial overlap/pressure is incorporated as much as is relevant.

9. Conclusion & discussion

This chapter looks back, concludes and discusses the research performed.

9.1. Conclusion

In this research an analysis method for the analysis of offshore wind opportunities in the Dutch offshore area has been designed. The main research question was: *What is a good analysis method for assessing the technical and economic feasibility of offshore wind farms in the Dutch offshore area?* In order to answer the research question the research design was based on 6 research steps. These steps answered the research question in roughly three phases. These phases are: actor analysis, analysis method design and input data analysis.

In the first phase, actor analysis, three points of interest requiring extra attention were identified. These points were: data quality, uniformity and spatial pressure and overlap. Throughout the research the points of interest were integrated in two methods. The first integration method was the incorporation in the form of factors in the analysis structure. The second integration method was the incorporation as part of the input data analysis. With the incorporation of the points of interest the designed analysis method takes the most pressing concerns of the offshore sector into account.

In the second phase, analysis method design, an analysis method for the analysis of the suitability of a location for offshore wind was designed. It was found that for a reliable analysis it is necessary to combine several research methods into one integral analysis. Oceanographic data coupled to foundation specifications and windfarm design, for example, improve the relevance and reliability of the output of the model. The coupling also has as beneficial effect that factors influencing other factors are held into account. In total the analysis structure incorporates 59 different factors and evaluation points. Together they form the design of the analysis model.

In the third phase, input data analysis, it was found that accuracy, reliability and data integrity was of significant influence on the reliability of the analysis model. Therefore a method for the evaluation of the required data was incorporated. The model evaluates if the data used as input are of value. This has been evaluated by setting minimal demands to the input data. Secondly the input data analysis method evaluates and indicates to which extent the data required to perform a complete analysis was present at the time the analysis was performed.

To conclude the research answers the main research question through the design of one integral analysis method based on two analysis models. One for the evaluation of the suitability of location for offshore wind and one for the evaluation of data input. With the combination of these two analysis models it is possible to perform an integral analysis of a location for offshore wind. The combination between location suitability and data input analysis is unique. No other method found in scientific literature has analysed offshore wind suitability on such an integral scale yet.

9.2. Discussion

Looking back on the research performed, the analysis structure which has been designed is the biggest strength of the research. But it also is the point of the research that could benefit the most from further research.

Improving the analysis structure by looking into the mathematical side of the analysis structure for a more in-depth analysis could have beneficial effects. Improvements can be achieved when looking into the most adequate formulas for the calculation at individual analysis points. One of the difficulties about making this improvement will be finding formulas and methods that have consensus in the scientific field. Due to time constrains, this improvement was unable to incorporated into this research. Furthermore the scope of this research was focussed on the factor selection, correlation, data analysis and design of the analysis model.

A second discussion point related to this research is data acquisition. During the research data acquisition was problematic. The disorder and fragmentation of offshore data is a serious problem in the sector. Next to the problems this causes for the sector itself, data fragmentation, inconstancies in data and disorder caused delays for the development of the analysis structure and data analysis method. Though this proved to have a delaying influence on the research. It at the same time strengthens the need for the data evaluation method posed in the research. If an attempt would be made to improve the problem with data acquisition in the sector the development of a data sharing platform for the offshore sector would probably have the greatest benefit. The design of a data sharing platform would significantly improve the data availability for future research into this topic and other topics in the offshore sector.

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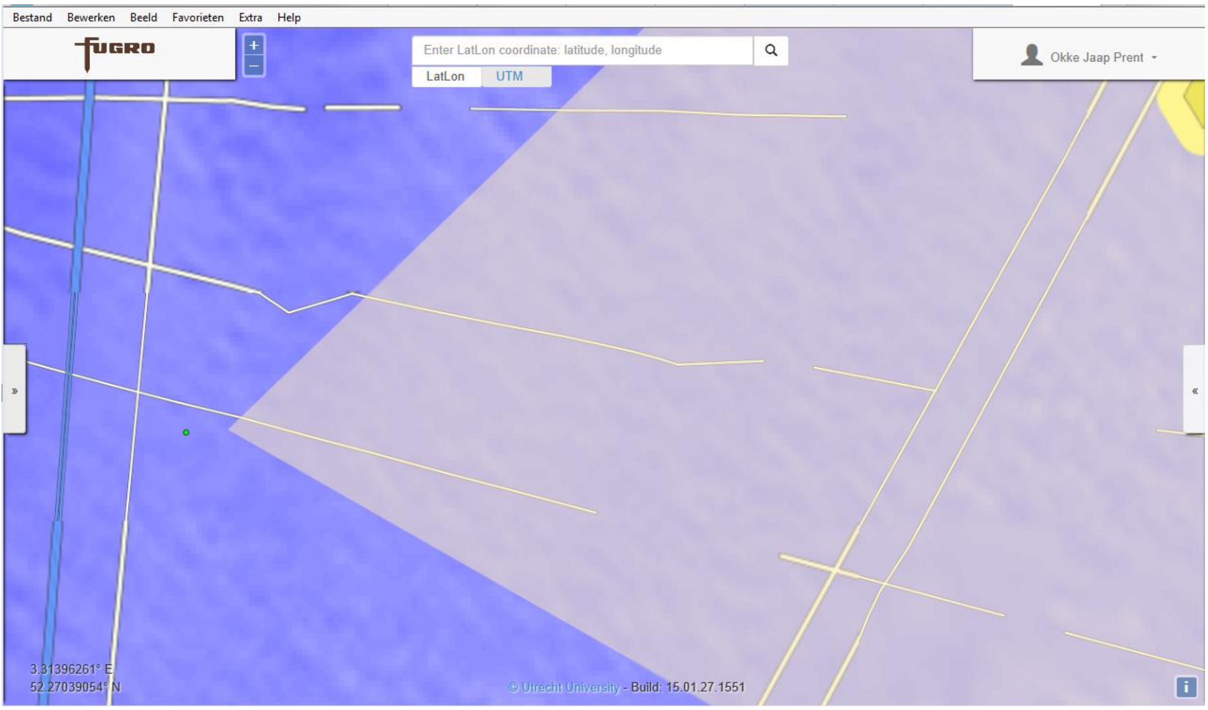
I. Appendix: spatial overlap

The lower figure shows an situation were confliction location positing occurs.

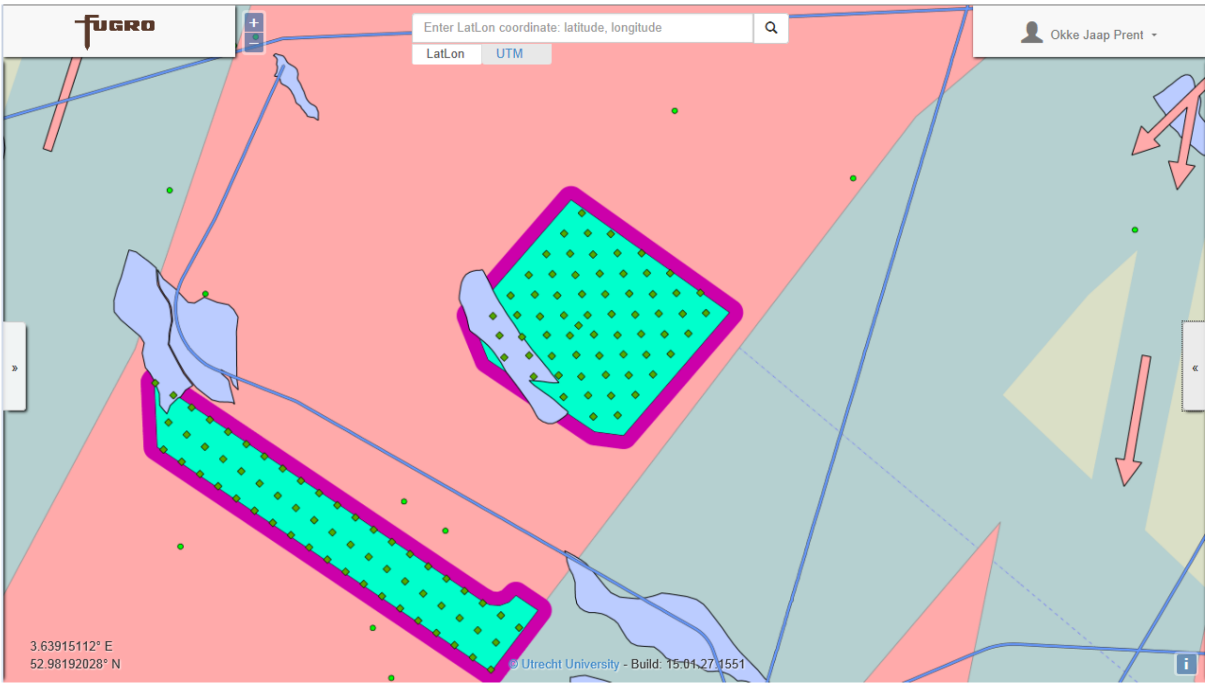


In the figure above the “white lines” indicate electricity cables on or in the seabed. The interruption of the line is an irregularity in the data. The electricity cable is a coaxial telecom cable.

The figure is based on the National Data Portal Offshore.

II. Appendix: spatial pressure

The figure below shows the overlapping position of a windfarm “on top” of a sub-surface hydrocarbon field.

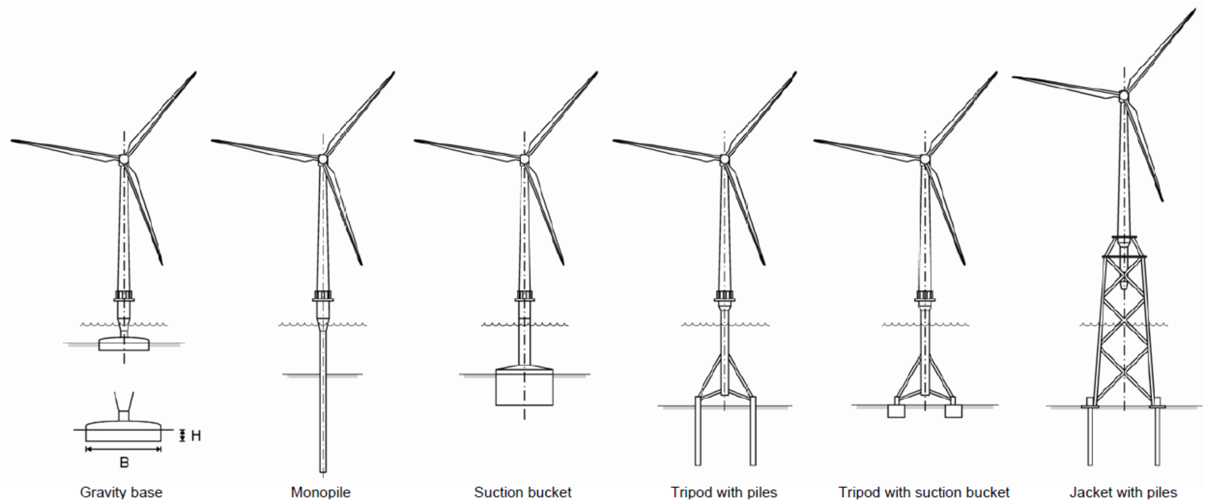


In the figure above the proposed windfarm Den Helder I is shown. The green dots would be the locations of individual windfarms when the windfarm is build. The light green is the area as it is permitted area of the windfarm and the purple outline is the safety area of the windfarm. Finally the blue area is the location of a hydro carbon field located “below” the windfarm area.
The positioning is based on GPS and is in correspondence with Dutch legislation.

The figure is based on the National Data Portal Offshore.

III. Appendix: foundation type differences

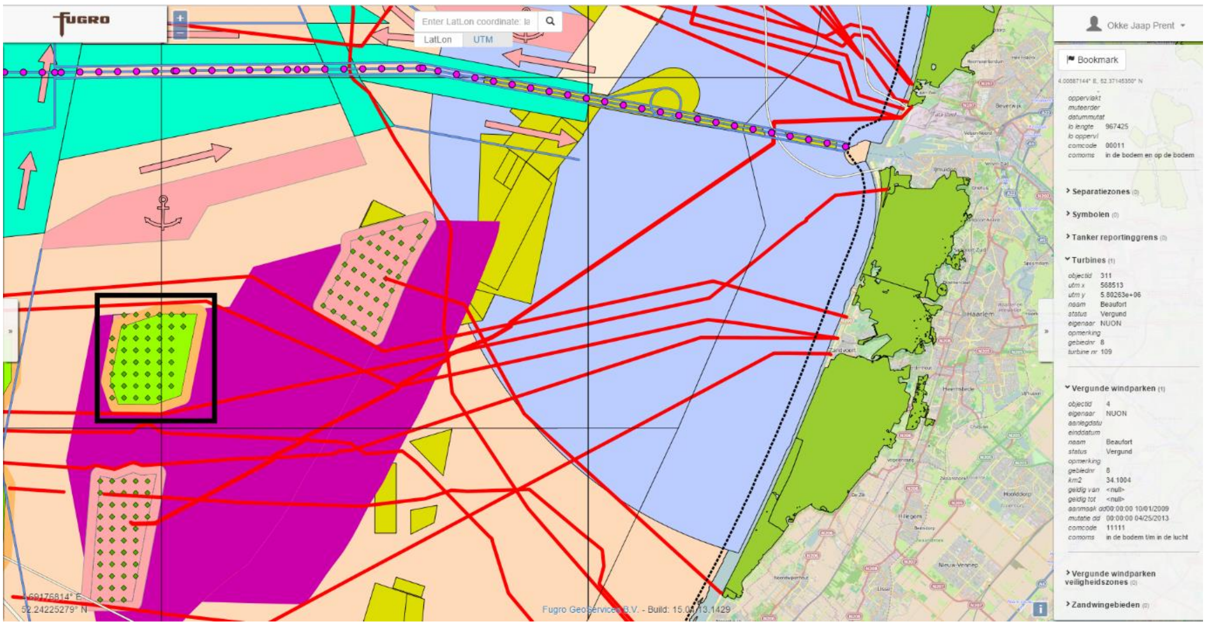
The figure below gives 6 examples of different foundation types. These foundation types vary in complexity and in requirements of the soil conditions.



The first foundation type is gravity based and only works in location with shallow water depth The second foundation type, monopole, is based on one straight foundation pile into the soil. Shallow water depth and low levels of wave alluvation can work for this foundation. The third foundation method is based on a suction bucket which makes a is fixed to a hard rock layer. The foundation is suitable for location with shallow rock layers and good climate conditions. The fourth foundation type is based on the same principle as the second. But increases the reliability through the use of multiple monopiles forming a tripod which is used as a foundation basis. The fifth combines the principle of the third and fourth. This foundation method is an strengthened version of the third making it possible to be applied in more extreme conditions than option three. The sixth, the most common method is the jacket with piles foundation type it combines the principle of the fourth foundation type and strengthens it with an reinforced jacket structure. This foundation basis can be used in the more extreme conditions.

IV. Appendix: data inconsistencies

The figure below shows an offshore wind farm indicated as: permitted. Data is provided by the national governments water division (Rijkswaterstaat) and can be considered unreliable.



The offshore wind park is highlighted with a black box. In the right menu the wrong indication of: “vergunde windparken” is shown.

The figure is based on the National Data Portal Offshore.

V. Appendix: analysis model overall

The figure below shows the analysis model as a whole.